(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 077 330 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 158(3) EPC

(43) Date of publication:
21.02.2001 Bulletin 2001/08

(21) Application number: **99931540.1**

(22) Date of filing: **26.07.1999**

(51) Int. Cl.^{7}: **F04B 43/02**

(86) International application number:
PCT/JP99/03995

(87) International publication number:
WO 00/52336 (08.09.2000 Gazette 2000/36)

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE

(30) Priority: **03.03.1999 JP 5626799**
15.03.1999 JP 6930199

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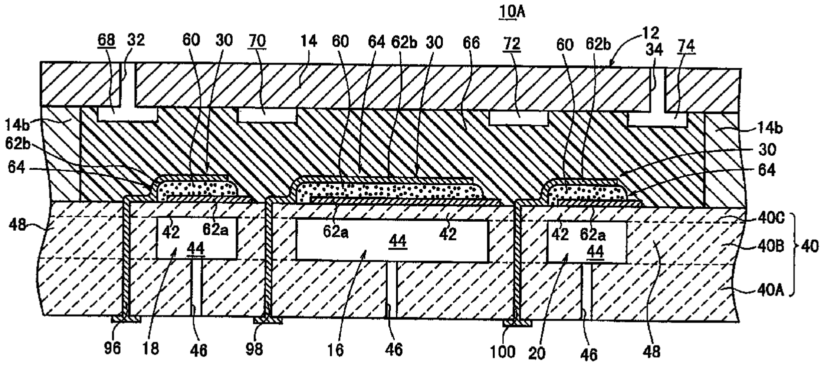
(54) **PUMP**

(57) A pump according to the present invention comprises the main pump body 12 including the casing 14 to which the fluid is supplied, and the input valve section 18, the pump section 16, and the output valve section 20 which are provided opposingly to the back surface of the casing 14, for selectively forming a flow passage on the back surface of the casing 14 in accordance with selective displacement action of the input valve section 18, the pump section 16, and the output valve section 20 in a direction to make approach or separation with respect to the back surface of the casing 14, wherein the fluid is controlled for its flow in accordance with the selective formation of the flow passage.

With the above arrangement, a pump can be of the compact and thin type, making it possible to increase the discharge amount (movement amount) of fluid.

FIG. 1



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Description

Technical Field

[0001] The present invention relates to a pump. In particular, the present invention relates to a pump which is preferably allowed to have a miniature and thin size.

Background Art

[0002] Recently, a microminiature pump has been suggested, in which the viscosity of a liquid is thermally changed so that the change in viscosity is utilized in place of the valve.

[0003] The microminiature pump has no mechanical value, and hence it involves no fear of abrasion and malfunction. It is approved that such a microminiature pump can be applied to a device to be embedded in the body to administer a trace amount of medicament and to a small-sized chemical analyzer.

[0004] It is considered that such a microminiature pump will be extensively applied in future, for example, to those concerning the medical field and the chemical analysis. In such application, it is of course important that the pump has a miniature and thin size. Further, it is desirable that the pump has a large discharge amount (movement amount) of fluid although it has the miniature and thin size.

[0005] Those made of silicon are known as such a microminiature pump. However, in the case of such a pump, the rigidity of vibrating section is small, and it is difficult to realize the high speed pumping operation and the increase in discharge amount (movement amount) of fluid.

[0006] The present invention has been made taking such a problem into consideration, an object of which is to provide a pump which has a miniature and thin size and which makes it possible to increase the discharge amount (movement amount) of fluid.

[0007] Another object of the present invention is to provide a pump which makes it possible to efficiently perform pressure reduction on the introducing side and pressure application on the discharge side.

Disclosure of Invention

[0008] According to the present invention, there is provided a pump comprising a main pump body including at least one pump section, for selectively forming a flow passage for a fluid in accordance with selective displacement action of the pump section in a direction to make approach or separation; wherein the fluid is controlled for its flow in accordance with the selective formation of the flow passage in the main pump body.

[0009] Specifically, the present invention is characterized in that the pump section includes at least one actuator section; and the actuator section comprises a shape-retaining layer, an operating section having at least one pair of electrodes formed on the shape-retaining layer, a vibrating section for supporting the operating section, and a fixed section for supporting the vibrating section in a vibrating manner.

[0010] Further, the present invention is characterized in that the pump section includes a displacement-transmitting section for transmitting the displacement action of the actuator section generated by applying a voltage to the pair of electrodes.

[0011] Accordingly, the pump can be of the compact and thin type, making it possible to increase the discharge amount (movement amount) of the fluid. Thus, it is possible to efficiently reduce the pressure on the introduction side and apply the pressure on the discharge side.

[0012] It is also preferable for the pump constructed as described above that a plurality of actuator sections are allotted corresponding to the displacement-transmitting section for the pump section.

[0013] Preferably, at least the vibrating section, of the vibrating section and the fixed section, is composed of ceramics. In this arrangement, it is also preferable that the vibrating section and the fixed section are formed in an integrated manner, and it is also preferable that the vibrating section and the fixed section are formed of ceramics in an integrated manner. Preferably, the operating section for constructing the actuator section is formed in an integrated manner together with the vibrating section and the fixed section.

[0014] It is also preferable that the shape-retaining layer is composed of a piezoelectric and/or electrostrictive layer and/or an anti-ferroelectric layer.

[0015] Preferably, a hollow space for allowing the vibrating section to be capable of vibration is provided at a portion of the fixed section corresponding to the vibrating section, and a through-hole is formed to make penetration from a second principal surface of the fixed section to the hollow space. Preferably, the through-hole is sealed.

[0016] It is also preferable that the main pump body comprises a plurality of pump sections connected in series. In this arrangement, it is also preferable that when the pump sections, which are adjacent to one another and which are connected in series, are driven, the pump section disposed on a discharge side is driven once while the pump section disposed on an introduction side is driven in a plurality of times so that the flow of the fluid is controlled.

[0017] Preferably, the main pump body is installed between an introduction side and a discharge side. In this arrangement, it is also preferable that a plurality of pump sections are connected in parallel on the introduction side. It Is also preferable that a plurality of pump sections are connected in parallel on the discharge side.

[0018] In another preferred arrangement, the main pump body comprises a plurality of pump sections connected in a branched configuration. In still another preferred arrangement, the main pump body comprises a plurality of pump sections connected in an arbitrary combination of series connection and parallel connection.

[0019] It is also preferable for the pump constructed as described above that the pump section is provided opposingly to a part of a surface of a casing to which the fluid is supplied; and the main pump body is operated such that the flow passage for the fluid is selectively formed on the part of the surface of the casing in accordance with the selective displacement action of the pump section in the direction to make approach or separation with respect to the part of the surface of the casing.

[0020] In this arrangement, an end surface of a displacement-transmitting section preferably contacts with the casing, or a gap is preferably formed between an end surface of a displacement-transmitting section and the casing, when the displacement of an actuator section of the pump section makes nearest approach to the casing.

[0021] It is preferable that the main pump body is supported with certain rigidity by at least the casing and/or a support pillar for supporting the casing. It is also preferable that the main pump body is supported with certain rigidity by at least the casing and/or an outer circumferential fixed section for supporting the casing.

[0022] According to a significant aspect of the present invention, a plurality of pump sections are installed opposingly to one another; an intermediate support plate is provided between the pump sections; and the main pump body selectively forms the flow passage for the fluid on a plate surface of the intermediate support plate in accordance with the selective displacement action of the pump sections in the direction to make approach or separation with respect to the plate surface of the intermediate support plate.

[0023] In this arrangement, it is also preferable that the main pump body is supported with certain rigidity by at least the intermediate support plate and/or a support pillar for supporting the intermediate support plate. It is preferable that the main pump body is supported with certain rigidity by at least the intermediate support plate and/or an outer circumferential fixed section for supporting the intermediate support plate.

[0024] Preferably, in the pump constructed as described above, a plurality of pump sections are installed opposingly to one another; and the main pump body selectively forms the flow passage for the fluid between the mutually opposing pump sections in accordance with the selective displacement action of the mutually opposing pump sections in the direction to make approach or separation.

[0025] In this arrangement, it is also preferable that the pump further comprises a casing for supplying the fluid thereto; wherein the main pump body is supported with certain rigidity by at least the casing and/or a support pillar for supporting the casing. It is preferable that the main pump body is supported with certain rigidity by at least the casing and/or an outer circumferential fixed section for supporting the casing.

[0026] It is also preferable for the pump constructed as described above that a plurality of pump sections are provided; and a valve section is allowed to intervene between the pump sections. Preferably, the plurality of pump sections are provided; and a set comprising the valve section disposed between the pump sections, and a set comprising no valve section disposed between the pump sections are arbitrarily combined.

[0027] In this arrangement, it is also preferable that the valve section comprises at least one valve actuator section provided opposingly to a part of a surface of a casing to which the fluid is supplied; and the flow of the fluid from the pump section disposed at an upstream stage to the pump section disposed at a downstream stage is controlled in accordance with the displacement action of the valve actuator section in the direction to make approach or separation with respect to the part of the surface of the casing.

[0028] It is also preferable for the pump constructed as described above that a plurality of valve sections are installed opposingly to one another; an intermediate support plate is provided between the valve sections; each of the valve sections comprises at least one valve actuator section provided opposingly to a plate surface of the intermediate support plate; and the flow of the fluid from the pump section disposed at an upstream stage to the pump section disposed at a downstream stage is controlled in accordance with the displacement action of the valve actuator section in the direction to make approach or separation with respect to the plate surface of the intermediate support plate.

[0029] It is also preferable for the pump constructed as described above that a plurality of valve sections are installed opposingly to one another; each of the valve sections comprises at least one valve actuator section provided opposingly to one another; and the flow of the fluid from the pump section disposed at an upstream stage to the pump section disposed at a downstream stage is controlled in accordance with the displacement action of the mutually opposing valve actuator section in the direction to make approach or separation.

[0030] It is also preferable for the pump constructed as described above that the plurality of valve actuator sections are allotted corresponding to a displacement-transmitting section for the valve section. Preferably, a displacement-transmitting section for an actuator section of the pump section is formed continuously with a displacement-transmitting section for the actuator section of the valve section. Preferably, a crosstalk-preventive section is formed between the displacement-transmitting section for the actuator section of the pump section and the displacement-transmitting section for the actuator section of the valve section.

[0031] It is also preferable for the pump constructed as described above that a vibrating section and a fixed section of an actuator section of the pump section and a vibrating section and a fixed section of the actuator section of the valve section are integrally formed of ceramics. Preferably, at least one of the valve sections has a shape of check valve.

[0032] In a preferred arrangement of the present invention constructed as described above, it is also preferable that the pump further comprises at least one input valve section disposed on an introduction side of the pump section.

[0033] In this arrangement, it is also preferable that the input valve section comprises at least one input valve actuator section provided opposingly to a part of a surface of a casing to which the fluid is supplied; and the flow of the fluid from the pump section disposed at an upstream stage to the pump section disposed at a downstream stage is controlled in accordance with the displacement action of the input valve actuator section in the direction to make approach or separation with respect to the part of the surface of the casing.

[0034] It is also preferable for the pump constructed as described above that a plurality of input valve sections are installed opposingly to one another; an intermediate support plate is provided between the input valve sections; each of the input valve sections comprises at least one input valve actuator section provided opposingly to a plate surface of the intermediate support plate; and the flow of the fluid from the pump section disposed at an upstream stage to the pump section disposed at a downstream stage is controlled in accordance with the displacement action of the input valve actuator section in the direction to make approach or separation with respect to the plate surface of the intermediate support plate.

[0035] It is also preferable for the pump constructed as described above that a plurality of input valve sections are installed opposingly to one another; each of the input valve sections comprises at least one input valve actuator section provided opposingly to one another; and the flow of the fluid from the pump section disposed at an upstream stage to the pump section disposed at a downstream stage is controlled in accordance with the displacement action of the mutually opposing input valve actuator sections in the direction to make approach or separation.

[0036] In another preferred arrangement, the plurality of input valve actuator sections are allotted corresponding to a displacement-transmitting section for the input valve section. In still another preferred arrangement, a displacement-transmitting section for an actuator section of the pump section is formed continuously with a displacement-transmitting section for the actuator section of the input valve section. Preferably, a crosstalk-preventive section is formed between the displacement-transmitting section for the actuator section of the pump section and the displacement-transmitting section for the actuator section of the input valve section.

[0037] It is also preferable for the pump constructed as described above that a vibrating section and a fixed section of an actuator section for the pump section and a vibrating section and a fixed section for the actuator section of the input valve section are integrally formed of ceramics. In a preferred arrangement, at least one of the input valve sections has a shape of check valve.

[0038] In another preferred arrangement of the present invention, the pump constructed as described above further comprises at least one output valve section disposed on a discharge side of the pump section.

[0039] In this arrangement, it is also preferable that the output valve section comprises at least one output valve actuator section provided opposingly to a part of a surface of a casing to which the fluid is supplied; and the flow of the fluid from the pump section disposed at an upstream stage to the pump section disposed at a downstream stage is controlled in accordance with the displacement action of the output valve actuator section in the direction to make approach or separation with respect to the part of the surface of the casing.

[0040] It is also preferable for the pump constructed as described above that a plurality of output valve sections are installed opposingly to one another; an intermediate support plate is provided between the output valve sections; each of the output valve sections comprises at least one output valve actuator section provided opposingly to a plate surface of the intermediate support plate; and the flow of the fluid from the pump section disposed at an upstream stage to the pump section disposed at a downstream stage is controlled in accordance with the displacement action of the output valve actuator section in the direction to make approach or separation with respect to the plate surface of the intermediate support plate.

[0041] It is also preferable for the pump constructed as described above that a plurality of output valve sections are installed opposingly to one another; each of the output valve sections comprises at least one output valve actuator section provided opposingly to one another; and the flow of the fluid from the pump section disposed at an upstream stage to the pump section disposed at a downstream stage is controlled in accordance with the displacement action of the mutually opposing output valve actuator sections in the direction to make approach or separation.

[0042] In a preferred arrangement, the plurality of output valve actuator sections are allotted corresponding to a displacement-transmitting section for the output valve section. Preferably, a displacement-transmitting section for an actuator section of the pump section is formed continuously with a displacement-transmitting section for the actuator section of the output valve section. Preferably, a crosstalk-preventive section is formed between the displacement-transmitting section for the actuator section of the pump section and the displacement-transmitting section for the actuator section of the output valve section.

[0043] It is also preferable for the pump constructed as described above that a vibrating section and a fixed section of an actuator section of the pump section and a vibrating section and a fixed section of the actuator section of the output valve section are integrally formed of ceramics. Preferably, at least one of the output valve sections has a shape of check valve.

[0044] According to another aspect of the present invention, there is provided a pump comprising a main pump body including at least one input valve section, at least one pump section, and at least one output valve section, for selectively forming a flow passage for a fluid in accordance with selective displacement action of the input valve section, the pump section, and the output valve section in a direction to make approach or separation; wherein the fluid is controlled for its flow in accordance with the selective formation of the flow passage in the main pump body.

[0045] In this arrangement, it is also preferable that the input valve section, the pump section, and the output valve section are provided opposingly to a part of a surface of a casing to which the fluid is supplied; and the main pump body is operated such that the flow passage for the fluid is selectively formed on the part of the surface of the casing in accordance with the selective displacement action of the input valve section, the pump section, and the output valve section in the direction to make approach or separation with respect to the part of the surface of the casing.

[0046] It is also preferable for the pump constructed as described above that a plurality of input valve sections, a plurality of pump sections, and a plurality of output valve sections are installed opposingly to one another; an intermediate support plate is provided between the input valve sections, between the pump sections, and between the output valve sections; and the main pump body is operated such that the flow passage for the fluid is selectively formed on a plate surface of the intermediate support plate in accordance with the selective displacement action of the input valve sections, the pump sections, and the output valve sections in the direction to make approach or separation with respect to the plate surface of the intermediate support plate.

[0047] It is also preferable for the pump constructed as described above that a plurality of input valve sections, a plurality of pump sections, and a plurality of output valve sections are installed opposingly to one another; and the main pump body is operated such that the flow passage for the fluid is selectively formed between the input valve sections, the pump sections, and the output valve sections which are opposed to one another in accordance with the selective displacement action of the input valve sections, the pump sections, and the output valve sections which are opposed to one another, in the direction to make approach or separation.

[0048] In a preferred arrangement, the flow passage is formed when both of the input valve section and the pump section which are adjacent to one another are operated, when both of the pump sections which are adjacent to one another are operated, or when both of the pump section and the output valve section which are adjacent to one another are operated.

[0049] It is also preferable for the pump constructed as described above that a communication passage is formed to make a bypass between the flow passage formed between the input valve section and the pump section which are adjacent to one another and the flow passage formed between the pump sections which are adjacent to one another, and make a bypass between the flow passage formed between the pump sections which are adjacent to one another and the flow passage formed between the pump section and the output valve section which are adjacent to one another.

[0050] According to still another aspect of the present invention, there is provided a pump comprising a main pump body including at least one input valve section, a plurality of pump sections, at least one valve section installed between the plurality of pump sections, and at least one output valve section, for selectively forming a flow passage for a fluid in accordance with selective displacement action of the input valve section, the pump sections, the valve section, and the output valve section in a direction to make approach or separation; wherein the fluid is controlled for its flow in accordance with the selective formation of the flow passage in the main pump body.

[0051] In this arrangement, it is also preferable that the input valve section, the pump sections, the valve section, and the output valve section are provided opposingly to a part of a surface of a casing to which the fluid is supplied; and the main pump body is operated such that the flow passage for the fluid is selectively formed on the part of the surface of the casing in accordance with the selective displacement action of the input valve section, the pump sections, the valve section, and the output valve section in the direction to make approach or separation with respect to the part of the surface of the casing.

[0052] It is also preferable for the pump constructed as described above that a plurality of input valve sections, a plurality of pump sections, a plurality of valve sections, and a plurality of output valve sections are installed opposingly to one another; an intermediate support plate is provided between the input valve sections, between the pump sections, between the valve sections, and between the output valve sections; and the main pump body is operated such that the flow passage for the fluid is selectively formed on a plate surface of the intermediate support plate in accordance with the selective displacement action of the input valve sections, the pump sections, the valve sections, and the output valve sections in the direction to make approach or separation with respect to the plate surface of the intermediate support plate.

[0053] It is also preferable for the pump constructed as described above that a plurality of input valve sections, a plurality of pump sections, a plurality of valve sections, and a plurality of output valve sections are installed opposingly to one another; and the main pump body is operated such that the flow passage for the fluid is selectively formed between the input valve sections, the pump sections, the valve sections, and the output valve sections which are opposed to one another in accordance with the selective displacement action of the input valve sections, the pump sections, the valve sections, and the output valve sections which are opposed to one another, in the direction to make approach or separation.

[0054] Preferably, the flow passage is formed when both of the input valve section and the pump section which are adjacent to one another are operated, when both of the pump section and the valve section which are adjacent to one another are operated, or when both of the pump section and the output valve section which are adjacent to one another are operated.

[0055] It is also preferable for the pump constructed as described above that a communication passage is formed to make a bypass between the flow passage formed between the input valve section and the pump section which are adjacent to one another and the flow passage formed between the pump sections which are adjacent to one another, and make a bypass between the flow passage formed between the pump sections which are adjacent to one another and the flow passage formed between the pump section and the output valve section which are adjacent to one another.

[0056] According to still another aspect of the present invention, there is provided a pump comprising a main pump body including at least one input valve section, a plurality of pump sections some of which belong to a set including a valve section intervening between the pump sections that are adjacent to one another and the other of which belong to a set including no valve section intervening between the pump sections that are adjacent to one another, and at least one output valve section, for selectively forming a flow passage for a fluid in accordance with selective displacement action of the input valve section, the pump sections, the valve section, and the output valve section in a direction to make approach or separation; wherein the fluid is controlled for its flow in accordance with the selective formation of the flow passage in the main pump body.

[0057] In this arrangement, it is also preferable that the input valve section, the pump sections, the valve section, and the output valve section are provided opposingly to a part of a surface of a casing to which the fluid is supplied; and the main pump body is operated such that the flow passage for the fluid is selectively formed on the part of the surface of the casing in accordance with the selective displacement action of the input valve section, the pump sections, the valve section, and the output valve section in the direction to make approach or separation with respect to the part of the surface of the casing.

[0058] It is also preferable for the pump constructed as described above that a plurality of input valve sections, a plurality of pump sections, a plurality of valve sections, and a plurality of output valve sections are installed opposingly to one another; an intermediate support plate is provided between the input valve sections, between the pump sections, between the valve sections, and between the output valve sections; and the main pump body is operated such that the flow passage for the fluid is selectively formed on a plate surface of the intermediate support plate in accordance with the selective displacement action of the input valve sections, the pump sections, the valve sections, and the output valve sections in the direction to make approach or separation with respect to the plate surface of the intermediate support plate.

[0059] It is also preferable for the pump constructed as described above that a plurality of input valve sections, a plurality of pump sections, a plurality of valve sections, and a plurality of output valve sections are installed opposingly to one another; and the main pump body is operated such that the flow passage for the fluid is selectively formed between the input valve sections, the pump sections, the valve sections, and the output valve sections which are opposed to one another in accordance with the selective displacement action of the input valve sections, the pump sections, the valve sections, and the output valve sections which are opposed to one another, in the direction to make approach or separation.

[0060] Preferably, the flow passage is formed when both of the input valve section and the pump section which are adjacent to one another are operated, when both of the pump section and the valve section which are adjacent to one another are operated, or when both of the pump section and the output valve section which are adjacent to one another are operated.

[0061] It is also preferable for the pump constructed as described above that a communication passage is formed to make a bypass between the flow passage formed between the input valve section and the pump section which are adjacent to one another and the flow passage formed between the pump sections which are adjacent to one another, and make a bypass between the flow passage formed between the pump sections which are adjacent to one another and the flow passage formed between the pump section and the output valve section which are adjacent to one another.

Brief Description of Drawings

[0062]

FIG. 1 shows a sectional view illustrating a pump according to a first embodiment.
FIG. 2 shows a plan view illustrating a main pump body with a casing being removed, concerning the pump according to the first embodiment.
FIG. 3 shows a sectional view illustrating a state in which the depth of a hollow space is decreased in the pump according to the first embodiment.
FIG. 4 shows a sectional view illustrating a portion including a support pillar, concerning the pump according to the first embodiment.
FIG. 5 shows an example of the planar configuration of a pair of electrodes formed on an actuator section.
FIG. 6A illustrates an example of comb teeth of the pair of electrodes arranged along the major axis of a shape-retaining layer.
FIG. 6B illustrates another example.
FIG. 7A illustrates an example of comb teeth of the pair of electrodes arranged along the minor axis of the shape-retaining layer.
FIG. 7B illustrates another example.
FIG. 8 shows a sectional view illustrating an example in which the shape-retaining layer is provided with a pair of electrodes and an intermediate layer.
FIG. 9 shows a sectional view illustrating an example in which an introducing hole and a discharge hole are formed just over an input valve section and an output valve section respectively, concerning the pump according to the first embodiment.
FIG. 10 shows a plan view of the main pump body depicted with the casing being removed, in the example in which the introducing hole and the discharge hole are formed just over the input valve section and the output valve section respectively.
FIG. 11 illustrates a state in which the input valve section and a pump section are driven, concerning the pump according to the first embodiment.
FIGS. 12A to 12F illustrates the operation of the pump according to the first embodiment.
FIG. 13 illustrates an example in which the input valve section and the pump section are driven to form flow passages at the input valve section and the pump section.
FIG. 14 illustrates an example in which the pump section and the output valve section are driven to form flow passages at the pump section and the output valve section.
FIG. 15 shows a sectional view illustrating an example in which a gap is formed between an end surface of a displacement-transmitting section and a back surface of the casing in the pump according to the first embodiment.
FIG. 16 shows a cross-sectional arrangement illustrating a pump according to a first modified embodiment concerning the first embodiment.
FIG. 17 illustrates a state in which the pump according to the first modified embodiment concerning the first embodiment is operated.
FIG. 18 shows a cross-sectional arrangement illustrating a pump according to a second modified embodiment concerning the first embodiment.
FIG. 19 shows a cross-sectional arrangement illustrating a pump according to a third modified embodiment concerning the first embodiment.
FIG. 20 shows a cross-sectional arrangement illustrating a pump according to a fourth modified embodiment concerning the first embodiment.
FIG. 21 shows a cross-sectional arrangement illustrating a pump according to a fifth modified embodiment concerning the first embodiment.
FIG. 22 shows a cross-sectional arrangement illustrating a pump according to a sixth modified embodiment concerning the first embodiment.
FIG. 23 shows a cross-sectional arrangement illustrating a pump according to a seventh modified embodiment concerning the first embodiment.
FIG. 24 shows a cross-sectional arrangement illustrating a pump according to an eighth modified embodiment concerning the first embodiment.
FIG. 25 shows a sectional view illustrating a pump according to a second embodiment.
FIG. 26 shows a sectional view illustrating another exemplary pump according to the second embodiment.
FIG. 27 shows a sectional view illustrating a pump according to a first modified embodiment concerning the second embodiment.
FIG. 28 shows a plan view illustrating a main pump body with a casing being removed, concerning the first modified

embodiment of the pump according to the second embodiment.

FIG. 29 shows a plan view illustrating a main pump body with a casing being removed, concerning a second modified embodiment of the pump according to the second embodiment.

FIG. 30 shows a sectional view illustrating a pump according to a third embodiment.

FIG. 31 shows a model illustrating the pump according to the third embodiment.

FIG. 32 shows a driving sequence for the pump according to the third embodiment.

FIG. 33 shows a model illustrating a first modified embodiment of the pump according to the third embodiment.

FIG. 34 shows a model Illustrating a second modified embodiment of the pump according to the third embodiment.

FIG. 35 shows a model illustrating a third modified embodiment of the pump according to the third embodiment.

FIGS. 36A to 36C show models illustrating fourth modified embodiments of the pump according to the third embodiment.

FIG. 37 shows a sectional view illustrating a fifth modified embodiment of the pump according to the third embodiment.

FIG. 38 shows a model illustrating the pressure-reducing operation effected by a fifth modified embodiment of the pump according to the third embodiment.

FIG. 39 shows a model illustrating the pressure-applying operation effected by the fifth modified embodiment of the pump according to the third embodiment.

FIG. 40A shows a sectional view illustrating a sixth modified embodiment of the pump according to the third embodiment.

FIG. 40B shows a sectional view illustrating a situation in which a first pump section is operated in the sixth modified embodiment of the pump according to the third embodiment.

FIG. 41 shows a plan view illustrating a main pump body with a casing being removed, concerning a seventh modified embodiment of the pump according to the third embodiment.

FIG. 42A shows a sectional view illustrating a pump according to a fourth embodiment.

FIG. 42B shows a sectional view illustrating a situation in which a pump section is operated in the pump according to the fourth embodiment.

FIG. 43 shows a sectional view illustrating a pump according to a fifth embodiment.

FIG. 44 shows a sectional view illustrating a modified embodiment of the pump according to the fifth embodiment.

FIG. 45 shows a sectional view illustrating a pump according to a sixth embodiment.

FIG. 46 shows a sectional view illustrating a pump according to a seventh embodiment.

FIGS. 47A to 47D illustrate the operation of the pump according to the seventh embodiment.

Best Mode for Carrying Out the Invention

[0063] Several illustrative embodiments of the pump according to the present invention will be explained below with reference to FIGS. 1 to 47D.

[0064] As shown in FIG. 1, a pump 10A according to a first embodiment has a main pump body 12. The main pump body 12 comprises a casing 14 to which a fluid is supplied, a pump section 16, an input valve section 18, and an output valve section 20 which are provided to opposed to one surface in the casing 14. Each of the pump section 16, the input valve section 18, and the output valve section 20 has an actuator section 30.

[0065] That is, the pump 10A according to the first embodiment comprises the casing 14 to which the fluid is supplied, the input valve section 18, the pump section 16, and the output valve section 20 which are provided to oppose to the back surface of the casing 14, and the main pump body 12 for selectively forming the flow passage on the back surface of the casing 14 in accordance with the selective displacement action in the direction to make approach or separation of the input valve section 18, the pump section 16, and the output valve section 20 with respect to the back surface of the casing 14. The pump 10A is constructed such that the flow of the fluid is controlled in accordance with the selective formation of the flow passage.

[0066] In the present invention, the term "selective formation of the flow passage" indicates an arbitrary combination of expansion/contraction or opening/closing operation of the pump section 16, the input valve section 18, or the output valve section 20 for effecting the discharge (or pressure application or pressure reduction).

[0067] The casing 14 is formed with an introducing hole 32 for supplying the fluid and a discharge hole 34 for discharging the fluid. As shown in FIG. 2, the input valve section 18, the pump section 16, and the output valve section 20 are arranged in the lateral direction between the introducing hole 32 and the discharge hole 34. In FIG. 2, the region indicated by reference numeral 130 is a portion which is not movable as the input valve section 18, the pump section 16, and the output valve section 20, of an entire portion composed of a constitutive material of a displacement-transmitting section 66 charged between the casing 14 and a substrate 40, i.e., the portion which does not directly participate in the transmittance of displacement of the actuator section 30.

[0068] The main pump body 12 includes the substrate 40 composed of, for example, ceramics. The substrate 40 has its first principal surface which is arranged to oppose to the back surface of the casing 14. The first principal surface is a continuous surface (flushed surface). Hollow spaces 44, which are used to form vibrating sections 42 at positions corresponding to the pump section 16, the input valve section 18, and the output valve section 20 respectively as described later on, are provided at the inside of the substrate 40. Each of the hollow space 44 communicates with the outside via a through-hole 46 having a small diameter provided through the second end surface of the substrate 40.

[0069] Portions of the substrate 40, at which the hollow spaces 44 are formed, are thin-walled. The other portions of the substrate 40 are thick-walled. The thin-walled portion has a structure which is suitable to receive the vibration effected by the external stress, and it functions as the vibrating section 42. The portion other than the hollow space 44 is thick-walled, and it functions as a fixed section 48 for supporting the vibrating section 42.

[0070] That is, the substrate 40 has a stacked structure comprising a substrate layer 40A as a lowermost layer, a spacer layer 40B as an intermediate layer, and a thin plate layer 40C as an uppermost layer. The substrate 40 can be recognized as an integrated structure including the hollow spaces 44 formed through the spacer layer 40B at the positions corresponding to the pump section 16, the input valve section 18, and the output valve section 20 respectively.

[0071] The spacer layer 40B can be optionally formed to be thin as shown, for example, in FIG. 3 by means of a technique represented, for example, by the screen printing method. Such an arrangement is desirable in view of realization of the thin size of the pump 10A and improvement in characteristics of the actuator section 30.

[0072] The substrate layer 40A functions as a reinforcing substrate, and it functions as a substrate for electric wiring as well. The substrate 40 may be formed as a simultaneously integrated sintered product, an integrated product obtained by joining the respective layers by using glass and resin, or a product obtained by additional attachment. In the instance described above, the substrate 40 has the three-layered structure. However, the substrate 40 may have a structure including four or more layers.

[0073] As shown in FIGS. 2 and 4, a plurality of support pillars 50, which are disposed in the vicinity of the actuator sections 30, Intervene between the casing 14 and the substrate 40, and thus the rigid junction is maintained. As shown in FIGS. 1 and 3, the rigid junction may be maintained by using the outer circumferential fixed section 14b of the casing 14. In this case, it is not indispensable to provide the support pillar 50.

[0074] It is most desirable that the rigid junction is effected by using the support pillars 50 and the outer circumferential fixed section 14b of the casing 14 in combination in order to allow the pump 10 to have certain rigidity.

[0075] As shown in FIG. 1, each of the actuator sections 30 comprises the vibrating section 42 and the fixed section 48 described above as well as an operating section 64 including a shape-retaining layer 60 such as a piezoelectric/electrostrictive layer or an anti-ferroelectric layer formed directly on the vibrating section 42, and a pair of electrodes 62 (a lower electrode 62a and an upper electrode 62b) formed on upper and lower surfaces of the shape-retaining layer 60. The pair of electrodes 62 may have a structure in which they are formed on the upper and lower surfaces of the shape-retaining layer 60 as shown in FIG. 1, or they may have a structure in which they are formed on only the upper or lower surface of the shape-retaining layer 60.

[0076] When the pair of electrodes 62 are formed on only the upper surface of the shape-retaining layer 60, the pair of electrodes 62 may have the following planar configurations. That is, as shown in FIG. 5, it is preferable to adopt a configuration in which a large number of comb teeth face to one another in a complementary manner. Alternatively, it is possible to adopt, for example, a spiral configuration and a branched configuration as disclosed in Japanese Laid-Open Patent Publication No. 10-78549 as well.

[0077] When the planar configuration of the shape-retaining layer 60 is, for example, an elliptic configuration, and the pair of electrodes 60 are formed to have the comb-shaped configuration, for example, then the following forms are available. That is, as shown in FIGS. 6A and 6B, it is possible to use a form in which the comb teeth of the pair of electrodes 62 are arranged along the major axis of the shape-retaining layer 60. Further, as shown in FIGS. 7A and 7B, it is possible to use a form in which the comb teeth of the pair of electrodes 62 are arranged along the minor axis of the shape-retaining layer 60.

[0078] As shown in FIGS. 6A and 7A, it is possible to use the form in which the portion of the comb teeth of the pair of electrodes 62 is included in the planar configuration of the shape-retaining layer 60. Further, as shown in FIGS. 6B and 7B, it is possible to use the form in which the portion of the comb teeth of the pair of electrodes 62 protrudes from in the planar configuration of the shape-retaining layer 60. The form shown in FIGS. 6B and 7B is more advantageous in view of the bending displacement of the actuator section 30.

[0079] By the way, as shown in FIG. 1, for example, when the pair of electrodes 62 are arranged such that the upper electrode 62b is formed on the upper surface of the shape-retaining layer 60, and the lower electrode 62a is formed on the lower surface of the shape-retaining layer 60, it is possible to cause the bending displacement in the first direction so that the actuator section 30 is convex toward the hollow space 44, for example, as shown in FIG. 11. Alternatively, it is also possible to cause the bending displacement in the second direction so that the actuator section 44 is convex toward the casing 14.

[0080] The following arrangement is also available as shown in FIG. 8. That is, the pair of electrodes 62a, 62b are formed on the upper surface of the shape-retaining layer 60, and a metal film layer (i.e., an intermediate layer 200) is formed between the vibrating section 42 and the shape-retaining layer 60. The formation of the intermediate layer 200 makes it possible to enhance the displacement retention ratio to be about 70 %, probably because of the following reason.

[0081] That is, when the metal film layer (intermediate layer 200), which is soft at a high temperature, is allowed to intervene between the vibrating section 42 and the shape-retaining layer 60, the stress is possibly mitigated, which would be otherwise generated In the shape-retaining layer 60 due to any stress constraint of the vibrating section 42 during the process from the sintering step to the cooling step for the shape-retaining layer 60.

[0082] Those preferably used as a material for the intermediate layer 200 include Pt, Pd, and an alloy of the both. The thickness of the intermediate layer 200 is appropriately not less than 1 μm and not more than 10 μm. Preferably, the thickness is not less than 2 μm and not more than 6 μm, because of the following reason.

[0083] That is, if the thickness is less than 1 μm, the effect of stress mitigation as described above does not appear. If the thickness exceeds 10 μm, the intermediate layer 200 is peeled off from the vibrating section 42 due to any sintering contraction caused during the sintering step for the intermediate layer 200.

[0084] As shown in FIG. 1, the main pump body 12 comprises a displacement-transmitting section 66 formed on each of the actuator sections 30, for transmitting the displacement of each of the actuator sections 30 in the direction toward the back surface of the casing 14.

[0085] A circular recess 68 is formed just under the introducing hole 32 at the upper portion of the displacement-transmitting section 66. A rectangular recess 70 is formed between the input valve section 18 and the pump section 16. A rectangular recess 72 is formed between the pump section 16 and the output valve section 20. A circular recess 74 is formed just under the discharge hole 34.

[0086] As shown in FIGS. 9 and 10, the recesses 68, 74 can be omitted when the Introducing hole 32 and the discharge hole 34 are disposed just over the input valve section 18 and the output valve section 20 respectively. In this arrangement, in addition to the realization of the miniature size, it is also possible to improve the tight contact performance between the displacement-transmitting section 66 and casing 14 and improve the function as the valve.

[0087] In the natural state, the end surface of the displacement-transmitting section 66 contacts with the back surface of the casing 14 in the pump 10A according to the first embodiment shown in FIGS. 1 and 3. Starting from this state, for example, when a control voltage indicating "open" is applied to the upper electrode 62b of the input valve section 18, then the actuator section 30 of the input valve section 18 makes bending displacement to be convex toward the hollow space 44, i.e., makes bending displacement in the first direction as shown, for example, in FIG. 11, and the end surface of the displacement-transmitting section 66 corresponding to the input valve section 18 is separated from the back surface of the casing 14. Thus, a flow passage 90, which communicates with the introducing hole 32, is formed at a portion corresponding to the input valve section 18.

[0088] After that, when a control voltage indicating "open" is applied to the upper electrode 62b of the pump section 16, then the actuator section 30 of the pump section 16 makes bending displacement to be convex toward the hollow space 44 as shown in FIG. 11, i.e., makes bending displacement in the first direction, and the end surface of the displacement-transmitting section 66 corresponding to the pump section 16 is separated from the back surface of the casing 14. Thus, flow passages 90, 92, which communicate with the introducing hole 32, are formed at portions corresponding to the input valve section 18 and the pump section 16. The same operation is performed for the output valve section 20 by supplying the control voltage.

[0089] When the application of the control voltage, for example, to the pump section 16 and the input valve section 18 is stopped, for example, then the end surface of the displacement-transmitting section 66 corresponding to the pump section 16 and the input valve section 18 contacts with the back surface of the casing 14 again, and the flow passages 90, 92 described above are closed. In other words, the actuator section 30, which is possessed, for example, by the input valve section 18 and the pump section 16, functions as a flow passage-forming means for selectively forming, for example, the flow passages 90, 92 at the portions corresponding to the input valve section 18 and the pump section 16.

[0090] In a preferred embodiment, the input valve section 18 and the output valve section 20 are constructed such that large rigidity is obtained while ensuring a displacement amount in a degree to reliably form the flow passage. Accordingly, it is also possible to avoid any fluid leakage. On the other hand, the pump section 16 is preferably constructed such that the displacement amount is increased to obtain a large change in volume while maintaining a certain degree of rigidity. The construction as described above can be controlled by the area, the thickness, and the material of the vibrating section 42, the area and the thickness of the shape-retaining layer 60, and the area of at least the pair of electrodes 62.

[0091] On the other hand, when the pair of electrodes 62 are formed and constructed on only the upper surface of the shape-retaining layer 60, or when the anti-ferroelectric is used as the shape-retaining layer 60, then the end surface of the displacement-transmitting section 66 is in a state of being separated from the back surface of the casing 14 in the natural state. Therefore, a control voltage indicating "close" is applied to each of the upper electrodes 62b of the input valve section 18, the pump section 16, and the output valve section 20 at the point of time of start of the operation. Accordingly, the bending displacement is effected so that each of the actuator sections 30 is convex toward the back surface of the casing 14, i.e., in the second direction. Thus, the respective end surfaces of the input valve section 18, the pump section 16, and the output valve section 20 contact with the back surface of the casing 14 beforehand.

[0092] The application of the control voltage to the input valve section 18, the pump section 16, and the output valve section 20 is selectively stopped to restore the actuator section 30 to the original state. Thus, for example, the flow passages 90, 92 are selectively formed at the portions corresponding to the input valve section 18 and the pump section 16 in an appropriate manner. Alternatively, for example, as for the pump section 16, the pair of electrodes 62 may be formed on only the upper surface of the shape-retaining layer 60, and as for the input valve section 18 and the output valve section 20, the upper electrode 62b and the lower electrode 62a may be formed on the upper and lower surfaces of the respective shape-retaining layers 60. It is also possible to use an arrangement in which the components are formed in an inverted manner as compared with the above. When the arrangement as described above is adopted, then the displacement of the actuator section can be enlarged, and the discharge amount of the pump section 16 can be increased, which is desirable.

[0093] The voltage is supplied to the respective lower electrodes 62a of the pump section 16, the input valve section 18, and the output valve section 20 via a common wiring 94 disposed in the lateral direction of the casing 14. In this case, the common wiring 94 is connected to GND, or an offset voltage is supplied by the aid of a power source. In this arrangement, when a voltage (negative voltage in a direction opposite to the polarization direction) to generate the displacement in the second direction (displacement to be convex toward the back surface of the casing 14) is applied as the offset voltage to the actuator section 30, it is possible to make reliable contact between the casing 14 and the displacement-transmitting section 66.

[0094] On the other hand, the voltage is supplied to the respective upper electrodes 62b of the pump section 16, the input valve section 18, and the output valve section 20 via through-holes 96, 98, 100 from an unillustrated wiring board (stuck to the second principal surface of the substrate 40) respectively. As described above, it is also possible to allow the second principal surface of the substrate 40 (second principal surface of the substrate layer 40A) to have the function of the wiring board.

[0095] An unillustrated insulative film, which is composed of, for example, a silicon oxide film, a glass film, a ceramic film, or a resin film, is allowed to intervene at portions of intersection between the wiring connected to the respective lower electrodes 62a and the wiring connected to the respective upper electrodes 62b in order to effect mutual insulation between the wirings. It is a matter of course that the formation of the insulative film is unnecessary in some cases depending on the way of wiring.

[0096] Next, explanation will be made for each of the constitutive members of the actuator section 30, especially for the selection of, for example, the material of each of the constitutive members, and the formation of the actuator section 30. The formation of the actuator section 30 is described, for example, in Japanese Laid-Open Patent Publication Nos. 3-128681, 5-49270, 8-51241, 8-107238, and 10-190086, an example of which will be explained below.

[0097] At first, the vibrating section 42 is preferably made of a highly heat-resistant material, because of the following reason. That is, when the operating section 64 is joined to the vibrating section 42, a structure is used, in which the vibrating section 42 is directly supported without using any material such as an organic adhesive which is inferior in heat resistance. In such a case, the vibrating section 42 is preferably made of a highly heat-resistant material, in order that the quality of the vibrating section 42 is not changed at least during the process for forming the shape-retaining layer 60.

[0098] The vibrating section 42 is preferably made of an electrically insulative material in order to electrically separate the wiring connected to the lower electrode 62a of the pair of electrodes 62 formed on the substrate 40 from the wiring connected to the upper electrode 62b.

[0099] Therefore, the vibrating section 42 may be made of a material such as highly heat-resistant metal or porcelain enamel with its metal surface coated with a ceramic material such as glass. However, ceramics is most appropriate.

[0100] Those usable as the ceramics for constructing the vibrating section 42 include, for example, stabilized zirconium oxide, aluminum oxide, magnesium oxide, titanium oxide, spinel, mullite, aluminum nitride, silicon nitride, glass, and a mixture thereof. Especially, It is desirable to use aluminum oxide and stabilized zirconium oxide in view of the strength and the rigidity. The stabilized zirconium oxide is especially preferred, for example, because of the fact that the mechanical strength is high even when the thickness of the vibrating section 42 is thin, the toughness is high, and the chemical reactivity is small with respect to the shape-retaining layer 60 and the pair of electrodes 62. The term "stabilized zirconium oxide" includes stabilized zirconium oxide and partially stabilized zirconium oxide. The stabilized zirconium oxide has, for example, a cubic crystalline structure, and hence it does not cause any phase transition.

[0101] On the other hand, the zirconium oxide causes phase transition between the cubic and the tetragonal at about 1000 °C, and the crack is sometimes formed during the phase transition. The stabilized zirconium oxide contains 1 to 30 molar % of a stabilizer such as calcium oxide, magnesium oxide, yttrium oxide, scandium oxide, ytterbium oxide, cerium oxide, and oxide of rare earth metal. In order to enhance the mechanical strength of the vibrating section 42, it is preferable that the stabilizer contains yttrium oxide. In this case, the yttrium oxide is preferably contained in an amount of 1.5 to 6 molar %, more preferably 2 to 4 molar %. Further, it is preferable to contain aluminum oxide in an amount of 0.1 to 5 molar %.

[0102] The crystalline phase may be, for example, a mixed phase of cubic + monoclinic, a mixed phase of tetragonal + monoclinic, or a mixed phase of cubic + tetragonal + monoclinic. Especially, those having a major crystalline phase composed of tetragonal or a mixed phase of tetragonal + cubic are most preferred in view of the strength, the toughness, and the durability.

[0103] When the vibrating section 42 is composed of ceramics, a large number of crystal grains constitute the vibrating section 42. In order to enhance the mechanical strength of the vibrating section 42, the average particle size of the crystal grain is preferably 0.05 to 2 μm, more preferably 0.1 to 1 μm.

[0104] The fixed section 48 is preferably composed of ceramics. However, the fixed section 48 may be composed of the same ceramic material as that of the vibrating section 42, or it may be composed of a ceramic material different from that of the vibrating section 42. Those usable as the ceramics for constructing the fixed section 48 include, for example, stabilized zirconium oxide, aluminum oxide, magnesium oxide, titanium oxide, spinel, mullite, aluminum nitride, silicon nitride, glass, and a mixture thereof, in the same manner as the material for the vibrating section 42.

[0105] Especially, those preferably adopted for the substrate 40 to be used for the pump 10A according to the first embodiment include, for example, a material containing a major component of zirconium oxide, a material containing a major component of aluminum oxide, and a material containing a major component of a mixture thereof. Especially, those containing a major component of zirconium oxide are preferred. Clay or the like is sometimes added as a sintering aid. However, it is necessary to regulate the aid component so that those liable to form glass such as silicon oxide and boron oxide are not contained in an excessive amount, because of the following reason. That is, although the material liable to form glass is advantageous to join the substrate 40 and the shape-retaining layer 60, it facilitates the reaction between the substrate 40 and the shape-retaining layer 60, and it is difficult to maintain a predetermined composition of the shape-retaining layer 60. As a result, such a material, causes deterioration of element characteristics.

[0106] That is, it is preferable that the silicon oxide or the like in the substrate 40 is restricted to be not more than 3 %, preferably not more than 1 % in a weight ratio. It is noted that the major component refers to a component which exists in a ratio of not less than 50 % in a weight ratio.

[0107] In order to provide the pair of electrodes 62 and the shape-retaining layer 60 on the vibrating section 42 so that the operating section 64 is formed, a variety of known film formation techniques are appropriately adopted. However, when the shape-retaining layer 60 is formed, various thick film formation techniques are preferably adopted, including, for example, those based on screen printing, spray, coating, dipping, application, and electrophoresis, because of the following reason.

[0108] That is, when the thick film formation technique is used, it is possible to form the film on the outer surface of the vibrating section 42 of the substrate 40 by using a paste or a slurry containing a major component of, for example, piezoelectric/electrostrictive ceramic particles having an average particle size of about 0.01 μm to 7 μm, preferably about 0.05 μm to 5 μm. Thus, it is possible to obtain good element characteristics.

[0109] Among the thick film formation techniques, the screen printing method is used especially preferably in view of the fact that the fine patterning can be formed inexpensively. In order to obtain, for example, large displacement at a low operation voltage, it is desirable that the thickness of the shape-retaining layer 60 is preferably not more than 50 μm, more preferably not less than 3 μm and not more than 40 μm.

[0110] The electrophoresis method typically makes it possible to form the film at a high density with a high shape accuracy, as well as it has features as described in technical literatures of "DENKI KAGAKU 53, No. 1 (1985), pp. 63-68, written by Kazuo ANZAI" and "Proceedings of First Symposium on Higher-Order Ceramic Formation Method Based on Electrophoresis (1998), pp. 5-6 and pp. 23 to 24". Therefore, it is advantageous to appropriately select the various techniques considering, for example, the required accuracy and the reliability.

[0111] The electrode material for constructing the pair of electrodes 62 is not specifically restricted provided that the material is a conductor capable of withstanding the oxidizing atmosphere at a high temperature. For example, the material may be a metal simple substance or an alloy. Further, no problem occurs at all even when the material is a mixture of a insulative ceramics and a metal simple substance or an alloy thereof.

[0112] Those more preferably used include electrode materials containing a major component of a noble metal having a high melting point such as platinum, palladium, and rhodium, or an alloy such as silver-palladium, silver-platinum, and platinum-palladium. Alternatively, those preferably used include cermet materials composed of platinum and a substrate material, for example, a piezoelectric/electrostrictive material.

[0113] Among them, it is more preferable and desirable to use a material composed of only platinum or containing a major component of platinum alloy. The ratio of the substrate material added to the electrode material is preferably about 5 to 30 % by volume. The ratio of the piezoelectric/electrostrictive material is preferably about 5 to 20 % by volume.

[0114] The pair of electrodes 62 are formed respectively by using the electrode material as described above in accordance with the aforementioned thick film formation technique or the ordinary film formation method based on the thin film formation method such as sputtering, ion beam, vacuum deposition, ion plating, CVD, and plating. Especially, when the lower electrode 62a is formed, various thick film formation techniques are preferably adopted, including, for example, screen printing, spray, dipping, application, and electrophoresis. When the upper electrode 62b is formed, the thin film formation method described above is preferably adopted as well in addition to the thick film formation technique to be effected in the same manner as described above. In this embodiment, any of the lower electrode 62a and the upper electrode 62b is generally formed to have a thickness of not more than 20 μm, preferably not more than 5 μm.

[0115] The entire thickness of the operating section 64, which is obtained by adding the thickness of the shape-retaining layer 60 to the thicknesses of the lower electrode 62a and the upper electrode 62b, is generally not more than 100 μm, preferably not more than 50 μm.

[0116] When the piezoelectric/electrostrictive layer is used as the shape-retaining layer 60, those used for the piezoelectric/electrostrictive layer include, for example, materials containing a major component of lead zirconate lead titanate (PZT system), materials containing a major component of lead magnesium niobate (PMN system), materials containing a major component of lead nickel niobate (PNN system), materials containing a major component of lead zinc niobate, materials containing a major component of lead manganese niobate, materials containing a major component of lead magnesium tantalate, materials containing a major component of lead nickel tantalate, materials containing a major component of lead antimony stannate, materials containing a major component of lead titanate, materials containing a major component of lead magnesium tungstate, materials containing a major component of lead cobalt niobate, and composite materials containing a combination of any of the compounds described above. It is needless to say that the compound as described above is contained as a major component which occupies not less than 50 % by weight. Among the ceramics described above, the ceramics containing lead zirconate is most frequently used as the constitutive material for the piezoelectric/electrostrictive layer.

[0117] When the piezoelectric/electrostrictive layer is composed of the ceramics, those preferably used include materials obtained by appropriately adding, to the material described above, for example, oxides of lanthanum, barium, niobium, zinc, cerium, cadmium, chromium, cobalt, antimony, iron, yttrium, tantalum, tungsten, nickel, manganese, lithium, strontium, and bismuth, or a combination of any of them, or another compound, for example, those obtained by appropriately adding a predetermined additive to the material described above to provide, for example, the PLZT system.

[0118] Among the piezoelectric/electrostrictive materials described above, those advantageously used include, for example, materials containing a major component composed of lead magnesium niobate, lead zirconate, and lead titanate, materials containing a major component composed of lead nickel niobate, lead magnesium niobate, lead zirconate, and lead titanate, materials containing a major component composed of lead magnesium niobate, lead nickel tantalate, lead zirconate, and lead titanate, and materials containing a major component composed of lead magnesium tantalate, lead magnesium niobate, lead zirconate, and lead titanate, as well as those obtained by substituting a part of lead of the material as described above with strontium and/or lanthanum. These materials are recommended as the material to be used when the piezoelectric/electrostrictive layer is formed by the thick film formation technique such as the screen printing described above.

[0119] In the case of the piezoelectric/electrostrictive material of the multicomponent system, the piezoelectric/electrostrictive characteristics change depending on the composition of the components. However, it is preferable to use a composition in the vicinity of the phase boundary of the pseudo-cubic/tetragonal/ rhombohedral in the case of a three-component system material of lead magnesium niobate-lead zirconate-lead titanate and a four-component system material of lead magnesium niobate-lead nickel tantalate-lead zirconate-lead titanate or lead magnesium tantalate-lead magnesium niobate-lead zirconate-lead titanate which are preferably used in the embodiment of the present invention. Especially, those advantageously adopted include a composition comprising lead magnesium niobate: 15 to 50 molar %, lead zirconate: 10 to 45 molar %, and lead titanate: 30 to 45 molar %, a composition comprising lead magnesium niobate: 15 to 50 molar %, lead nickel tantalate: 10 to 40 molar %, lead zirconate: 10 to 45 molar %, and lead titanate: 30 to 45 molar %, and a composition comprising lead magnesium niobate: 15 to 50 molar %, lead magnesium tantalate: 10 to 40 molar %, lead zirconate: 10 to 45 molar %, and lead titanate: 30 to 45 molar %, because these compositions have a high piezoelectric constant and a high electromechanical coupling factor.

[0120] When the anti-ferroelectric layer is used as the shape-retaining layer 60, those desirably used as the anti-ferroelectric layer include those containing a major component of lead zirconate, those containing a major component comprising lead zirconate and lead stannate, those obtained by adding lanthanum oxide to lead zirconate, and those obtained by adding lead zirconate and/or lead niobate to a component comprising lead zirconate and lead stannate.

[0121] Especially, when the anti-ferroelectric film containing components composed of lead zirconate and lead stannate as represented by the following composition is applied to the actuator section 30 of the pump 10A according to the first embodiment, it is possible to drive the pump 10A at a relatively low voltage, which is especially preferred.

$$Pb_{0.99}Nb_{0.02}[(Zr_xSn_{1-x})_{1-y}Ti_y]_{0.98}O_3$$

wherein there are given $0.5 < x < 0.6$, $0.05 < y < 0.063$, $0.01 < Nb < 0.03$.

[0122] The anti-ferroelectric layer may be porous. When the anti-ferroelectric is porous, it is desirable that the porosity is not more than 30 %.

[0123] As described above, the shape-retaining layer 60 and the pair of electrodes 62, which are formed as films on the outer surface of the vibrating section 42 of the substrate 40, may be heat-treated (sintered) every time when the respective films are formed to give a structure integrated with the substrate, specifically with the vibrating section 42. Alternatively, the shape-retaining layer 60 and the pair of electrodes 62 may be formed, followed by simultaneous heat treatment (sintering) to simultaneously join the respective films to the vibrating section 42 in an integrated manner.

[0124] It is noted that the heat treatment (sintering) for the electrode film to obtain the integrated structure is sometimes unnecessary depending on the type of the technique for forming the pair of electrodes 62.

[0125] A temperature of about 500 °C to 1400 °C is generally adopted as the heat treatment (sintering) temperature for integrating the vibrating section 42 with the shape-retaining layer 60 and the pair of electrodes 62. Especially preferably, a temperature within a range of 1000 °C to 1400 °C is advantageously selected. Further, when the film-shaped shape-retaining layer 60 is heat-treated, it is preferable to perform the heat treatment (sintering) while controlling the atmosphere together with an evaporation source for the shape-retaining layer 60 so that the composition of the shape-retaining layer 60 is not unstable at a high temperature. Further, it is also recommended to adopt a technique in which an appropriate cover member is placed on the shape-retaining layer 60 to perform the sintering so that the surface of the shape-retaining layer 60 is not directly exposed to the sintering atmosphere. In this case, a member composed of a material similar to the material of the substrate is used as the cover member.

[0126] On the other hand, it is preferable that the displacement-transmitting section 66 has a hardness of such a degree that the displacement of the actuator section 30 can be directly transmitted in the direction toward the casing 14. Therefore, those preferably used as the material for the displacement-transmitting section 66 include, for example, rubber, organic resin, organic adhesive film, and glass. However, no problem occurs even when the electrode layer itself, the piezoelectric material, or the material such as ceramic as described above is used. Those most preferably used include organic resins of epoxy, acrylic, silicone, and polyolefine, mixtures thereof, and organic adhesive films. Further, it is also effective to mix each of them with a filler to suppress and control contraction upon curing.

[0127] The displacement-transmitting section 66 may be connected to the actuator section 30 as follows. That is, when the material as described above is used for the displacement-transmitting section 66, then the displacement-transmitting section 66 made of the material as described above is stacked by using an adhesive, or a method is used in which a solution, a paste, or a slurry of the material as described above is subjected to, for example, coating. More specifically, the displacement-transmitting section 66 is preferably formed on the operating section 64 by means of, for example, screen printing, dipping, spinner, gravure printing, dispenser, application, and application with brush.

[0128] When the displacement-transmitting section 66 is connected to the operating section 64, it is preferable that the material for the displacement-transmitting section 66 is also used as an adhesive. The displacement-transmitting section 66 may be provided as a single layer. Alternatively, it is also desirable that the displacement-transmitting section 66 is provided as multiple layers to control the adhesive function and the contact/separation function. Especially, when an organic adhesive film is used, it can be used as an adhesive by applying the heat, which is preferred.

[0129] Those used as the constitutive material for the casing 14 include, for example, glass, quartz, plastic such as acrylic resin, ceramics, and metal. Those preferably used for the casing 14 have a hardness of such a degree that no deformation occurs when the displacement-transmitting section 66 makes contact therewith, while making it possible to maintain the rigidity of, for example, the pump section 16 and the input valve section 18.

[0130] Those preferably used for the outer circumferential fixed section 14b of the casing 14 and the support pillar 50 can maintain the rigidity of, for example, the pump section 16 and the input valve section 18 as well. Those used as the constitutive material for the support pillar 50 include, for example, glass, quartz, resin, plastic such as acrylic resin, ceramics, and metal. Especially preferably, the support pillar 50 is formed of a material which has a quality similar to that of the displacement-transmitting section 66 but which is hard and difficult to be deformed as compared with the displacement-transmitting section 66, in order to ensure the contact and the separation effected by the displacement-transmitting section 66.

[0131] Next, the operation of the pump 10A according to the first embodiment will be briefly explained with reference to FIGS. 3, 12A to 12F. At first, starting from the initial state shown in FIG. 3, i.e., from the state in which no flow passage is formed between the displacement-transmitting section 66 and the casing 14, the control voltage is applied to the upper electrode 62b of the actuator section 30 of the input valve section 18. Accordingly, as shown in FIG. 12A, the input valve section 18 makes bending displacement in the first direction, and the end surface of the displacement-transmitting section 66 corresponding to the input valve section 18 is separated from the back surface of the casing 14. Thus, the flow passage 90, which communicates with the introducing hole 32, is formed at the portion corresponding to the input valve section 18. At this time, the portion of the flow passage 90 corresponding to the input valve section 18 has a low pressure. Therefore, the fluid, which exists at the outside of the casing 14, is introduced into the flow passage 90 via the introducing hole 32.

[0132] Subsequently, as shown in FIG. 12B, the control voltage is applied to the upper electrode 62b of the actuator section 30 of the pump section 16. Accordingly, the pump section 16 makes bending displacement in the first direction, and the end surface of the displacement-transmitting section 66 corresponding to the pump section 16 is separated from the back surface of the casing 14. Thus, the flow passage 92 is formed at the portion corresponding to the pump section 16. As a result, the flow passages 90, 92, which communicate with the introducing hole 32, the input valve section 18, and the pump section 16, are formed. At this time, as shown in FIG. 13 as well, the flow passage 92 of the flow passages 90, 92 corresponding to the pump section 16 has a low pressure. Therefore, the fluid, which has been introduced via the introducing hole 32, is introduced into the flow passage 92 formed over the pump section 16.

[0133] Subsequently, as shown in FIG. 12C, when the supply of the control voltage to the input valve section 18 is stopped, then the input valve section 18 is restored to the original position, and the end surface of the displacement-transmitting section 66 corresponding to the input valve section 18 contacts with the back surface of the casing 14. Accordingly, the flow passage 92 is formed at only the portion corresponding to the pump section 16. That is, the closed space 92 is formed by the input valve section 18 and the output valve section 20, giving a state in which the fluid is charged in the space 92.

[0134] Subsequently, as shown in FIG. 12D, the control voltage is applied to the upper electrode 62b of the actuator section 30 of the output valve section 20. Accordingly, the output valve section 20 makes bending displacement in the first direction, and the end surface of the displacement-transmitting section 66 corresponding to the output valve section 20 is separated from the back surface of the casing 14. Thus, the flow passage 102 is formed at the portion corresponding to the output valve section 20. As a result, the flow passages 92, 102, which communicate with the pump section 16, the output valve section 20, and the discharge hole 34, are formed.

[0135] Subsequently, as shown in FIG. 12E, when the supply of the control voltage to the pump section 16 is stopped, then the pump section 16 is restored to the original position, and the end surface of the displacement-transmitting section 66 corresponding to the pump section 16 contacts with the back surface of the casing 14. Accordingly, as shown in FIG. 14 as well, the fluid, which has been located at the pump section 16, is extruded toward the discharge hole 34, and the fluid is discharged to the outside of the casing 14.

[0136] Finally, as shown in FIG. 12F, when the supply of the control voltage to the output valve section 20 is stopped, then the output valve section 20 is restored to the original position, and the end surface of the displacement-transmitting section 66 corresponding to the output valve section 20 contacts with the back surface of the casing 14. Accordingly, the remaining fluid, which has been located at the output valve section 20, is extruded toward the discharge hole 34, and the fluid is discharged to the outside of the casing 14.

[0137] As described above, the pump 10A according to the first embodiment comprises the main pump body 12 including the casing 14 to which the fluid is supplied, and the input valve section 18, the pump section 16, and the output valve section 20 which are provided opposingly to the back surface of the casing 14, for selectively forming the flow passage on the back surface of the casing 14 in accordance with the selective displacement action of the input valve section 18, the pump section 16, and the output valve section 20 in the direction to make approach or separation with respect to the back surface of the casing 14, wherein the flow of the fluid is controlled by selectively forming the flow passage. Accordingly, it is possible to facilitate the realization of the miniature and thin size of the main pump body 12. Therefore, it is possible to make application to a variety of techniques including, for example, those concerning the medical field and the chemical analysis.

[0138] In the first embodiment, the actuator section 30, which is provided for the input valve section 18, the pump section 16, and the output valve section 20 respectively, comprises the shape-retaining layer 60, the operating section 64 having at least one pair of electrodes 62 formed on the shape-retaining layer 60, the vibrating section 42 for supporting the operating section 64, and the fixed section 48 for supporting the vibrating section 42 in a vibrating manner. Further, the displacement action of the actuator section 30, which is generated by applying the voltage to the pair of electrodes 62, is transmitted via the displacement-transmitting section 66 in the direction toward the casing 14. Therefore, the selective formation of the flow passage described above can be reliably effected. The selective formation of the flow passage can be easily effected by means of the electric operation. Further, it is possible to efficiently make the pressure reduction for the introducing side and the pressure application for the discharge side.

[0139] Especially, the vibrating section 42 and the fixed section 48 are made of ceramics. Therefore, the rigidity of the main pump body 12 is enhanced, and it is possible to achieve the high speed displacement action of the actuator section 30. This results in the increase in operation frequency of the displacement, making it possible to achieve the increase in discharge amount (movement amount) of the fluid. That is, in this embodiment, it is possible to realize the miniature size and the light weight of the main pump body 12, and it is possible to simultaneously realize the increase in discharge amount (movement amount) of the fluid.

[0140] According to the fact described above, the pump 10A concerning the first embodiment can be constructed as a pressure-applying pump and a pressure-reducing pump. It is possible to increase the attainable pressure and quicken the period required to arrive at the attainable pressure. Therefore, even when the atmosphere outside the casing 14 is at a reduced pressure, it is possible to sufficiently operate the input valve section 18, the pump section 16, and the output valve section 20.

[0141] The displacement of the actuator section 30 is transmitted via the displacement-transmitting section 66.

Therefore, it is possible to construct the input valve section 18 and the output valve section 20 which are excellent in sealing performance (tight contact performance). Especially, in the natural state (initial state), the end surface of the displacement-transmitting section 66 is allowed to make contact with the back surface of the casing 14. Therefore, it is unnecessary to provide any fluid pool in the main pump body 12. Thus, it is possible to further contemplate the miniature size.

[0142] The shape-retaining layer 60 is constructed by using the piezoelectric layer and/or the electrostrictive layer and/or the anti-ferroelectric layer. Therefore, it is possible to improve the response performance, and it IS possible to further facilitate the increase in operation frequency of the displacement as described above.

[0143] When the fluid is gas to be used in the pump 10A according to the first embodiment, it is desirable that the depth of the recesses 70, 72 formed on the both sides of the pump section 16 is preferably larger than 0 mm and not more than 0.1 mm in view of the security for the compressibility and the pressure reduction ratio, more desirably 0.1 μm to 10 μm in view of the security for the resistance of the flow passage, the compressibility, and the pressure reduction ratio.

[0144] The pump 10A according to the first embodiment is formed such that the end surface of the displacement-transmitting section 66 is allowed to make contact with the back surface of the casing 14 when the displacement of the actuator section 30 of the pump section 16 is in the state of making nearest approach to the back surface of the casing 14 (i.e., in the case of the natural state). Alternatively, as shown in FIG. 15, a gap 132 may be formed between the end surface of the displacement-transmitting section 66 and the back surface of the casing 14. In this arrangement, the compressibility and the pressure reduction ratio are lowered. However, this arrangement is advantageous in response performance. Especially, when liquid is used as the fluid, no problem occurs even when the gap 132 is provided, because of the importance of the change in volume of the flow passage.

[0145] Next, explanation will be made for several modified embodiments of the pump 10A according to the first embodiment with reference to FIGS. 16 to 24.

[0146] At first, as shown in FIG. 16, a pump 10Aa according to a first modified embodiment utilizes the so-called crosstalk in which the displacement actions of the input valve section 18 and the pump section 16 are actively transmitted to the adjoining portions, for example, without forming the rectangular recess 70 (see FIG. 3) in the displacement-transmitting section 66.

[0147] Accordingly, as shown in FIG. 17, when the input valve section 18 and the pump section 16 are simultaneously displaced in the first direction, the flow passages 90, 92, which communicate with each other, are formed from the introducing hole 32 to the pump section 16. This situation is also provided for the pump section 16 and the output valve section 20 in the same manner as described above.

[0148] When the fluid is gas, the flow passage can be optionally formed between the input valve section 18 and the pump section 16 and between the pump section 16 and the output valve section 20. In other words, the flow passage space disappears when it is unnecessary. Therefore, it is possible to increase the compressibility and the pressure reduction ratio between the casing 14 and the pump section 16, which is preferred.

[0149] As shown in FIG. 18, a pump 10Ab according to a second modified embodiment comprises a slit 110 which is provided, for example, between the input valve section 18 and the pump section 16 in the displacement-transmitting section 66 so that the crosstalk is not transmitted to adjoining portions to realize independent operation for the respective sections. In this embodiment, the provision of the slit 110 is not limited only for the displacement-transmitting section 66, but it may be also provided between the actuator sections 30 through the substrate 40. Of course, the rectangular recess 70 shown in FIGS. 1 and 3 also makes It possible to effectively avoid the crosstalk, which is desirable to further enhance the response performance.

[0150] As shown in FIG. 19, a pump 10Ac according to a third modified embodiment has a structure comprising the input valve section 18 disposed just under the introducing hole 32, and the output valve section 20 disposed just under the discharge hole 34. According to this structure, it is possible to further miniaturize the size of the main pump body 12.

[0151] As shown in FIG. 20, a pump 10Ad according to a fourth modified embodiment comprises the input valve section 18 disposed just under the introducing hole 32, in which the portion of the displacement-transmitting section 66 corresponding to the input valve section 18 is formed to have a ring-shaped configuration. The pump 10Ad further comprises the output valve section 20 disposed just under the discharge hole 34, in which the portion of the displacement-transmitting section 66 corresponding to the output valve section 20 is formed to have a ring-shaped configuration.

[0152] As shown in FIG. 21, a pump 10Ae according to a fifth modified embodiment is operated such that the fluid is introduced in the lateral direction along the back surface of the casing 14, and the fluid is discharged in the lateral direction along the back surface of the casing 14 as well.

[0153] As shown in FIG. 22, a pump 10Af according to a sixth modified embodiment comprises the input valve section 18 and the output valve section 20 each of which has a shape of a check valve.

[0154] Although the illustration is not shown, it is a matter of course that the pump 10Af is constructed as follows. That is, the input valve section 18 has a shape of a check valve, and the output valve section 20 is based on the use of the actuator section 30. Alternatively, the input valve section 18 is based on the use of the actuator section 30, and the output valve section 20 has a shape of a check valve.

[0155] As shown in FIG. 23, a pump 10Ag according to a seventh modified embodiment has the input valve section 18 which comprises a first input valve section 18a based on the use of the actuator section 30 shown in FIGS. 1 and 3 and a second input valve section 18b having the shape of the check valve shown in FIG. 22. Further, the output valve section 20 comprises a first output valve section 20a based on the use of the actuator section 30 shown in FIGS. 1 and 3 and a second output valve section 20b having the shape of the check valve shown in FIG. 22.

[0156] As shown in FIG. 24, a pump 10Ah according to an eighth modified embodiment is constructed in the same manner as the pump 10A according to the first embodiment. However, the former is different from the latter in that the pump section 16 is not single, but a plurality of pump sections 16 are provided and arranged between the input valve section 18 and the output valve section 20. In this embodiment, it is possible to greatly increase the discharge amount of the fluid discharged by effecting the main pump body 12 while maintaining the rigidity. It is also possible to efficiently feed the fluid.

[0157] Next, a pump 10B according to a second embodiment will be explained with reference to FIGS. 25 and 26.

[0158] As shown in FIG. 25 and 26, the pump 10B according to the second embodiment is constructed in approximately the same manner as the pump 10A according to the first embodiment. However, the former is different from the latter in that the through-hole 46 (see FIG. 1 or 3), which penetrates through the substrate layer 40A to communicate with the hollow space 44, is sealed, and the gap 132 is formed between the end surface of the displacement-transmitting section 66 and the back surface of the casing 14 when the displacement of the actuator section 30 of the pump section 16 makes nearest approach to the back surface of the casing 14.

[0159] As shown in FIG. 25, it is assumed that pressure of the flow passage 92 of the pump section 16 is P_1, and the pressure of the hollow space 44 of the pump section 16 is P_2. When the flow passage 92 of the pump section 16 is contracted to apply the pressure, the hollow space 44 is sealed (the through-hole 46 shown In FIG. 1 is sealed) beforehand so that there is given $P_2 \geq P_1$. Thus, it is possible to help the pressure-applying action of the pump section 16.

[0160] Further, as shown in FIG. 26, when the flow passage 92 of the pump section 16 is expanded to reduce the pressure, the hollow space 44 is sealed (the through-hole 46 shown in FIG. 1 is sealed) beforehand so that there is given $P_2 \leq P_1$. Thus, it is possible to help the pressure-reducing action of the pump section 16.

[0161] As described above, in the pump 10B according to the second embodiment, the through-hole 46 of the hollow space 44 is sealed so that the pressure in the hollow space 44 is a predetermined pressure. Accordingly, it is possible to help the operation of, for example, the pump section 16, the input valve section 18, and the output valve section 20. Thus, it is possible to improve the response performance.

[0162] Next, two modified embodiments of the pump 10B according to the second embodiment will be explained with reference to FIGS. 27 to 29.

[0163] At first, as shown in FIGS. 27 and 28, a pump 10Ba according to a first modified embodiment is constructed in approximately the same manner as the pump 10B according to the second embodiment. However, the former is different from the latter in the following points. That is, the introducing hole 32 is formed just over the input valve section 18, the discharge hole 34 is formed just over the output valve section 20, and the through-holes 46 (see FIG. 1) communicating with the respective hollow spaces 44 are sealed. Further, the pump section 16 includes a plurality of (three in the illustrated embodiment) actuator sections 30a to 30c, the input valve section 18 includes a plurality of (two in the illustrated embodiment) actuator sections 30a, 30b, and the output valve section 20 includes a plurality of (two in the illustrated embodiment) actuator sections 30a, 30b. As shown in FIG. 28, each of the actuator sections 30a to 30c may be constructed to have an oblong planar configuration.

[0164] Additionally, the gap 132 is formed between the end surface of the displacement-transmitting section 66 over the pump section 16 and the back surface of the casing 14 in a state in which the displacement of each of the actuator sections 30a to 30c of the pump section 16 makes nearest approach to the back surface of the casing 14.

[0165] Next, as shown in FIG. 29, a pump 10Bb according to a second modified embodiment is constructed in approximately the same manner as the pump 10Ba according to the first embodiment described above. However, the former is different from the latter in that the pump section 16 includes a plurality of (six in the illustrated embodiment) actuator sections 30a to 30f, the input valve section 18 includes a plurality of (four in the illustrated embodiment) actuator sections 30a to 30d, and the output valve section 20 includes a plurality of (four in the illustrated embodiment) actuator sections 30a to 30d.

[0166] As shown in FIG. 29, each of the actuator sections 30a to 30f is constructed to be a miniature actuator section having a shape which is short in the longitudinal direction as compared with the oblong actuator sections 30a to 30c of the pump 10Ba according to the first embodiment. In this arrangement, it is possible to avoid the disadvantage of enlargement of the entire size.

[0167] Each of the pumps 10Ba, 10Bb according to the first and second modified embodiments has the pump section 16, the input valve section 18, and the output valve section 20 each of which comprises the plurality of actuator sections. Therefore, it is possible to improve the rigidity of the pump section 16, the input valve section 18, and the output valve section 20.

[0168] Next, a pump 10C according to a third embodiment will be explained with reference to FIGS. 30 to 32.

[0169] As shown in FIG. 30, the pump 10C according to the third embodiment is constructed in the same manner as the pump 10Ah according to the eight modified embodiment (see FIG. 24). However, the former is different from the latter in that valve sections 120 are arranged between the pump sections 16 respectively.

[0170] In order to simplify the illustration, as shown in FIG. 31, the configuration of the pump section 16 is simply represented by a circle (◯), and each of the input valve section 18, the output valve section 20, and the valve section 120 is simply depicted by a vertical line (|).

[0171] As shown in FIG. 31, when the pump 10C is used, then the input side (the side of the input valve section 18) of the main pump body 12 is connected to the introduction side, and the output side (the side of the output valve section 20) of the main pump body 12 is connected to the discharge side. After that, the respective pump sections 16 are successively driven to allow the fluid to flow. During this process, if the introduction side is a closed space, the pressure of the closed space is reduced. Therefore, in this situation, the main pump body 12 functions as a pressure-reducing pump. On the other hand, if the discharge side is a closed space, the pressure of the closed space is increased. Therefore, in this situation, the main pump body 12 functions as a pressure-applying pump.

[0172] A driving sequence for the pump sections 16 (designated as the first to fourth pump sections 16a to 16d) is shown, for example, in FIG. 32. In Cycle 1, the first pump section 16a is driven twice to feed the fluid to the second pump section 16b. In Cycle 2 in the next step, the second pump section 16b is driven twice to feed the fluid to the third pump section 16c.

[0173] In Cycle 3 in the next step, the first pump section 16a is driven twice to feed the fluid to the second pump section 16b. Simultaneously, the third pump section 16c is driven twice to feed the fluid to the fourth pump section 16d.

[0174] In Cycle 4 in the next step, the second pump section 16b is driven twice to feed the fluid to the third pump section 16c. Simultaneously, the fourth pump section 16d is driven twice to discharge the fluid via the output valve section 20.

[0175] Subsequently, Cycle 3 and Cycle 4 are successively repeated in the same manner as described above. Thus, the fluid is successively fed to the first to fourth pump sections, and it is discharged via the output valve section 20.

[0176] Next, several modified embodiments of the pump 10C according to the third embodiment will be explained with reference to FIGS. 33 to 41.

[0177] As shown in FIG. 33, a pump 10Ca according to a first modified embodiment is constructed in the same manner as the pump 10C according to the third embodiment. However, the former is different from the latter in that a set 16A comprising the valve section 120 connected between the adjacent pump sections 16, and a set 16B comprising no valve section 120 connected between the adjacent pump sections 16 are arbitrarily combined and connected.

[0178] As shown in FIG. 34, a pump 10Cb according to a second modified embodiment is constructed in the same manner as the pump 10C according to the third embodiment. However, the former is different from the latter in that a plurality of pump sections 16 are connected in parallel on the introduction side, and a plurality of pump sections 16 are connected in a branched form toward the discharge side.

[0179] In this embodiment, as in the pump 10Ca according to the first modified embodiment shown in FIG. 33, it is also preferable to adopt an arbitrary combination of a set 16A comprising the valve section 120 connected between the adjacent pump sections 16, and a set 16B comprising no valve section 120 connected between the adjacent pump sections 16.

[0180] As shown in FIG. 35, a pump 10Cc according to a third modified embodiment is different in that a plurality of pump sections 16 are connected in parallel on the discharge side, and a plurality of pump sections 16 are connected in a branched form toward the introduction side. In this embodiment, it is also preferable to adopt the arrangement of the pump 10Ca according to the first modified embodiment shown in FIG. 33.

[0181] Further, as in a pump 10Cd according to a fourth modified embodiment shown in FIGS. 36A to 36C, it is also preferable to arbitrarily combine the series connection and the parallel connection of a plurality of pump sections 16 between the introduction side and the discharge side. In these cases, it is also preferable to adopt the arrangement of the pump 10Ca according to the first modified embodiment shown in FIG. 33.

[0182] Each of the pumps 10Ca to 10Cd according to the first to fourth modified embodiments is able to function as a pressure-reducing pump and a pressure-applying pump in the same manner as the pump 10C according to the third embodiment.

[0183] As shown in FIG. 37, a fifth modified embodiment lies in an arrangement comprising the input valve section 18, the first pump section 16a, the valve section 120, the second pump section 16b, and the output valve section 20. In this arrangement, explanation will now be made with reference to FIGS. 38 and 39 for the pressure-reducing operation and the pressure-applying operation effected by a pump 10Ce according to the fifth modified embodiment. In order to simply and conveniently illustrate the pressure-reducing operation and the pressure-applying operation effected by the pump 10Ce according to the fifth modified embodiment, FIGS. 38 and 39 diagrammatically depict the input valve section 18, the first pump section 16a, the valve section 120, the second pump section 16b, and the output valve section

20. In the following description, the volumes of the flow passages of the input valve section 18, the valve section 120, and the output valve section 20 are neglected.

[0184] At first, the pressure-reducing operation will be explained referring to numerical expressions as well. Explanation will be firstly made for the pump 10Ce according to the fifth modified embodiment, concerning a case in which the first pump section 16a on the introduction side is operated in a plurality of times to reduce the pressure to the limit by the aid of the first and second pump sections 16a, 16b.

[0185] In the initial state (Cycle 1), the input valve section 18, the valve section 120, and the output valve section 20 are in the closed state, and the flow passages of the first and second pump sections 16a, 16b are in the state of contraction. In this situation, both of tile pressures of the first and second pump sections 16a, 16b are at the initial value (for example, 1 atm). It is assumed that the volume of each of the flow passages of the first and second pump sections 16a, 16b during the contraction is vc, and the volume of each of the flow passages during the expansion is v0. In this embodiment, a relationship of $vc = \alpha \cdot v0$ holds, wherein α indicates the compressibility (> 1).

[0186] In Cycle 2 in the next step, when only the flow passage of the first pump section 16a is expanded in the state in which all of the input valve section 18, the valve section 120, and the output valve section 20 are closed, the pressure of the flow passage of the first pump section 16a is P_1/α.

[0187] In Cycle 3 in the next step, when the valve section 120 is in the open state, the flow passages of the first and second pump sections 16a, 16b communicate with each other. Accordingly, the second pump section 16b is subjected to pressure reduction. At this time, the pressure of the second pump section 16b is represented by the following expression (1).

$$P_2' = \frac{P_2 \times v_C + \frac{P_1}{\alpha} \times v_0}{v_C + v_0} = \frac{P_2 + P_1}{1 + \alpha} \qquad \cdots\cdots(1)$$

[0188] When the pressure is reduced to the limit by means of the plurality of times of operation of the first pump section 16a, the pressure of the second pump section 16b is represented by the following expression (2). It is noted that the second pump section 16b is not operated.

$$P_2^{\infty} = \frac{P_2^{\infty} + P_1}{(1 + \alpha)} \qquad \therefore P_2^{\infty} = \frac{1}{\alpha} P_1 \qquad \cdots\cdots(2)$$

[0189] When the multistage structure is provided, in which a large number of pump sections 16 are connected in series as in the pump 10C according to the third embodiment shown in FIG. 30, the pressure of the third pump section is represented by the following expression (3). Similarly, the pressure of the nth pump section is represented by the following expression (4).

$$P_3^{\infty} = \left(\frac{1}{\alpha}\right) P_2^{\infty} = \left(\frac{1}{\alpha}\right) \cdot \left(\frac{1}{\alpha}\right) \cdot P_1 \qquad (3)$$

$$P_n^{\infty} = \left(\frac{1}{\alpha}\right)^{n-1} \cdot P_1 \qquad (4)$$

[0190] At this point of time, as for the nth pump section itself, its flow passage has not been expanded. Therefore, in accordance with the expansion of the flow passage of the nth pump section, the pressure of the nth pump section is the pressure represented by the expression (5).

$$P_n^{\infty} = \left(\frac{1}{\alpha}\right)^{n-1} \cdot P_1 \times \left(\frac{1}{\alpha}\right) = \left(\frac{1}{\alpha}\right)^{n} \cdot P_1 \qquad (5)$$

[0191] According to the expression (5), it is understood that the pressure can be reduced limitlessly in principle owing to the use of the multistage structure of the pump sections 16.

[0192] Next, explanation will be made for a case in which a large number of pump sections 16 are connected in series, and the respective pump sections 16 are allowed to perform the expanding action once to reduce the pressure.

[0193] The following expression (6) is derived from the expression (1) described above. It is noted that the second pump section itself is not operated.

$$P_2' = \frac{P_2 + P_1}{1+\alpha} = \frac{P_2}{1+\alpha} + \frac{P_1}{1+\alpha} = \frac{1}{1+\alpha} + \frac{1}{1+\alpha} \qquad (6)$$

(P_1 and P_2 have initial values of 1 atm.)

[0194] Similarly, concerning the third pump section and the second pump section, the pressure of the third pump section is represented by the following expression (7).

$$P_3' = \frac{P_3 + P_2'}{1+\alpha} = \frac{P_3 + \frac{P_2 + P_1}{1+\alpha}}{1+\alpha} = \frac{1}{1+\alpha} + \frac{1}{(1+\alpha)^2} + \frac{1}{(1+\alpha)^2} \quad \cdots\cdots (7)$$

(P_1, P_2, and P_3 have initial values of 1 atm.)

[0195] Similarly, concerning the nth pump section and the (n-1)th pump section, the pressure of the nth pump section is represented by the following expression (8).

$$P_n' = \sum_{k=1}^{n-1} \frac{1}{(1+\alpha)^k} + \frac{1}{(1+\alpha)^{n-1}} = \frac{1}{\alpha} + \left(1 - \frac{1}{\alpha}\right) \cdot \left(\frac{1}{1+\alpha}\right)^{n-1} \qquad (8)$$

[0196] Further, in view of the expansion of the nth pump section itself, the pressure of the nth pump section is represented by the following expression (9).

$$P_n'' = \frac{P_n'}{\alpha} = \frac{1}{\alpha^2} + \frac{\alpha - 1}{\alpha^2} \cdot \left(\frac{1}{1+\alpha}\right)^{n-1} \quad \cdots\cdots (9)$$

[0197] According to the expression (9), it is understood that when the pump sections 16 are provided in the multiple stages, the reduced pressure is converged on the limit value of $1/\alpha^2$.

[0198] Next, the pressure-applying operation will be explained with reference to numerical expressions as well. At first, explanation will be made for the pump 10Ce according to the fifth modified embodiment, concerning a case in which the first pump section 16a on the introduction side is operated in a plurality of times to apply the pressure to the limit by the aid of the first and second pump sections 16a, 16b.

[0199] In the initial state (Cycle 1), the input valve section 18, the valve section 120, and the output valve section 20 are in the closed state, and the flow passages of the first and second pump sections 16a, 16b are in the state of expansion.

[0200] In Cycle 2 in the next step, when only the flow passage of the first pump section 16a is contracted in the state in which all of the input valve section 18, the valve section 120, and the output valve section 20 are closed, the pressure of the flow passage of the first pump section 16a is αP_1.

[0201] In Cycle 3 in the next step, when the valve section 120 is in the open state, the flow passages of the first and second pump sections 16a, 16b communicate with each other. Accordingly, the second pump section 16b is subjected to pressure application. At this time, the pressure of the second pump section 16b is represented by the following expression (10).

$$P_2' = \frac{P_2 v_0 + \alpha P_1 v_c}{v_0 + v_c} = \frac{\alpha(P_2 + P_1)}{1+\alpha} \qquad (10)$$

[0202] When the pressure is applied to the limit by means of the plurality of times of operation of the first pump section 16a, the pressure of the second pump section 16b is represented by the following expression (11). It is noted that the second pump section 16b is not operated.

$$P_2^{\infty} = \frac{\alpha(P_2^{\infty} + P_1)}{(1+\alpha)} \qquad \therefore P_2^{\infty} = \alpha P_1 \qquad \cdots\cdots(11)$$

[0203] When the multistage structure is provided, in which a large number of pump sections 16 are connected in series as in the pump 10C according to the third embodiment shown in FIG. 30, the pressure of the third pump section is represented by the following expression (12). Similarly, the pressure of the nth pump section is represented by the following expression (13).

$$P_3^{\infty} = \alpha P_2^{\infty} = \alpha^2 \cdot P_1 \qquad (12)$$

$$P_n^{\infty} = \alpha^{n-1} \cdot P_1 \qquad (13)$$

[0204] At this point of time, as for the nth pump section itself, its flow passage has not been expanded. Therefore, in accordance with the expansion of the flow passage of the nth pump section, the pressure of the nth pump section is the pressure represented by the expression (14).

$$P_n^{\infty} = \alpha^{n-1} \cdot P_1 \times \alpha = \alpha^n \cdot P_1 \qquad (14)$$

[0205] According to the expression (14), it is understood that the pressure can be increased limitlessly in principle owing to the use of the multistage structure of the pump sections 16.

[0206] Next, explanation will be made for a case in which a large number of pump sections 16 are connected in series, and the respective pump sections 16 are allowed to perform the expanding action once to apply the pressure.

[0207] The following expression (15) is derived from the expression (10) described above. It is noted that the second pump section itself is not operated.

$$P_2' = \frac{\alpha(P_2 + P_1)}{1+\alpha} = \frac{\alpha}{1+\alpha} + \frac{\alpha}{1+\alpha} \qquad (15)$$

(P_1 and P_2 have initial values of 1 atm.)

[0208] Similarly, concerning the third pump section and the second pump section, the pressure of the third pump section is represented by the following expression (16).

$$P_3' = \frac{\alpha(P_3 + P_2')}{1+\alpha} = \frac{\alpha\left(P_3 + \frac{\alpha(P_2 + P_1)}{1+\alpha}\right)}{1+\alpha} = \frac{\alpha}{1+\alpha} + \frac{\alpha^2}{(1+\alpha)^2} + \frac{\alpha^2}{(1+\alpha)^2} \qquad \cdots\cdots(16)$$

(P_1, P_2, and P_3 have initial values of 1 atm.)

[0209] Similarly, concerning the nth pump section and the (n-1)th pump section, the pressure of the nth pump section is represented by the following expression (17).

$$P_n' = \sum_{k=1}^{n-1} \frac{\alpha^k}{(1+\alpha)^k} + \frac{\alpha^{n-1}}{(1+\alpha)^{n-1}} = \alpha + (1-\alpha) \cdot \frac{\alpha^{n-1}}{(1+\alpha)^{n-1}} \qquad (17)$$

[0210] Further, in view of the expansion of the nth pump section itself, the pressure of the nth pump section is represented by the following expression (18).

$$P_n''=\alpha \bullet P_n'=\alpha^2+(\alpha-\alpha^2) \bullet \frac{\alpha^{n-1}}{(1+\alpha)^{n-1}} \quad (18)$$

[0211] According to the expression (18), it is understood that when the pump sections 16 are provided in the multiple stages, the applied pressure is converged on the limit value of α^2.

[0212] Next, as shown in 40A, a pump 10Cf according to a sixth embodiment is constructed in the same manner as the pump 10Ce according to the fifth embodiment (see FIG. 37). However, the former is different from the latter in that the gap 132 is formed between the end surface of the displacement-transmitting section 66 and the back surface of the casing 14 at the portions corresponding to the first and second pump sections 16a, 16b and the valve section 120 when the displacement of each of the actuator sections 30 of the first and second pump sections 16a, 16b and the valve section 120 makes nearest approach to the back surface of the casing 14.

[0213] The pump 10Cf according to the sixth modified embodiment is preferably used irrelevant to whether the fluid is gas or liquid, because of the following reason.

[0214] That is, the pump 10Cf according to the sixth modified embodiment has the displacement-transmitting section 66 which does not make contact with the casing 14. Therefore, the first and second pump sections 16a, 16b can be operated at a high speed.

[0215] Further, for example, if there is no gap 132 between the casing 14 and the displacement-transmitting section 66 for the second pump section 16b in the contracted state, the flow passage 140 is not subjected to the pressure reduction even if the first pump section 16a is operated to make expansion. In such an arrangement, the pressure reduction can be effected up to a region before the second pump section 16b (see Interval A in FIG. 40B). Therefore, such an arrangement is disadvantageous when the pressure reduction is subsequently effected by the expansion of the second pump section 16b.

[0216] Accordingly, when the gap 132 is formed between the casing 14 and the displacement-transmitting section 66 for the second pump section 16b in the contracted state as in the pump 10Cf according to the sixth modified embodiment, the pressure reduction can be effected up to the flow passage 140 in accordance with the expanding operation of the first pump section 16a as shown in FIG. 40B. As described above, the flow passage 140 can be subjected to the pressure reduction before the expansion of the second pump section 16b. Therefore, the pump 10Cf according to the sixth embodiment is advantageous during the contraction process effected by the expansion of the second pump section 16b. This feature is also advantageous when the pressure is applied.

[0217] Next, as shown in FIG. 41, a pump 10Cg according to a seventh modified embodiment is constructed in the same manner as the pump 10C according to the third embodiment. However, the former is different from the latter in that a communication passage 146 is formed to make a bypass among the flow passage (recess) 70 formed between the input valve section 18 and the first pump section 16a which are adjacent to one another, the flow passage (recess) 142 formed between the first pump section 16a and the valve section 120 which are adjacent to one another, the flow passage (recess) 144 formed between the valve section 120 and the second pump section 16b which are adjacent to one another, and the flow passage (recess) 72 formed between the second pump section 16b and the output valve section 20 which are adjacent to one another.

[0218] In this embodiment, the gap 132 is not formed between the displacement-transmitting section 66 and the casing 14 upon the contraction of the first and second pump sections 16a, 16b.

[0219] The formation of the communication passage 146 makes it possible to previously reduce or apply the pressure for the portion of the flow passage on the discharge side by the aid of the communication passage 146, in the same manner as in the pump 10Cf according to the sixth modified embodiment. Accordingly, all of the flow passages, which are disposed in the region ranging from the introduction side to the discharge side, can be collectively subjected to the pressure application or the pressure reduction in an identical manner. Therefore, this embodiment is advantageous to effect the pressure reduction and the pressure application.

[0220] By the way, for example, the pump 10A according to the first embodiment has been constructed such that the recesses 70, 72 for constructing the flow passages are provided at the respective portions of the end surface of the displacement-transmitting section 66 between each of the input valve section 18, the pump section 16, and the output valve section 20. Alternatively, the following arrangement is also preferable as in a pump 10D according to a fourth embodiment shown in FIG. 42A. That is, the end surface of the displacement-transmitting section 66 is made to be flat (flushed surface), and spacers 150 are formed on the back surface of the casing 14. Thus, the flow passages corresponding to the recesses 70, 72 are successfully formed.

[0221] In this embodiment, as shown in FIG. 42B, for example, when the actuator section 30 of the pump section 16 is operated to expand the pump section 16, then the displacement-transmitting section 66 corresponding to the pump section 16 is separated from the spacer 150, and the flow passage 92 is formed just under the spacer 150 of the pump section 16.

[0222] Next, a pump 10E according to a fifth embodiment will be explained with reference to FIG. 43.

[0223] The pump 10E according to the fifth embodiment is constructed such that two main pump bodies (first and second main pump bodies 12A, 12B), each of which is constructed in the same manner as the main pump body 12 of the pump 10A according to the first embodiment, are stuck to one another with an intermediate support plate 160 being interposed therebetween, wherein their displacement-transmitting sections 66a, 66b are disposed opposingly to the intermediate support plate 160 respectively. The intermediate support plate 160 is fixed and interposed by the fixed section 14b which is disposed at the outer circumference of the casing 14.

[0224] Specifically, the first main pump body 12A includes the first input valve section 18a, the first pump section 16a, the first output valve section 20a, and the first displacement-transmitting section 66a. The second main pump body 12B includes the second input valve section 18b, the second pump section 16b, the second output valve section 20b, and the second displacement-transmitting section 66b.

[0225] The first and second input valve sections 18a, 18b are opposed to one another, the first and second pump sections 16a, 16b are opposed to one another, and the first and second output valve sections 20a, 20b are opposed to one another, while interposing the intermediate support plate 160 therebetween respectively. Further, the first and second displacement-transmitting sections 66a, 66b are arranged such that they abut against the intermediate support plate 160 respectively. The first and second introducing holes 32a, 32b are formed on the respective introduction sides of the first and second input valve sections 18a, 18b, through the outer circumferential fixed section 14b of the casings 14 respectively. The first and second discharge holes 34a, 34b are formed on the respective discharge sides of the first and second output valve sections 20a, 20b respectively.

[0226] In this embodiment, it is preferable that the first and second main pump bodies 12A, 12B are supported with certain rigidity by using the intermediate support plate 160 and/or unillustrated support pillars for supporting the intermediate support plate 160. Alternatively, it is also preferable that the first and second main pump bodies 12A, 12B are supported with certain rigidity by using the intermediate support plate 160 and/or the outer circumferential fixed section 14b for supporting the intermediate support plate 160.

[0227] In the pump 10E according to the fifth embodiment, the fluid is successively fed by selectively forming the flow passage for the fluid on the plate surface of the intermediate support plate 160 in accordance with the selective displacement action of the first and second input valve sections 18a, 18b, the first and second pump sections 16a, 16b, and the first and second output valve sections 20a, 20b in the direction to make approach or separation with respect to the plate surface of the intermediate support plate 160.

[0228] The pump 10E according to the fifth embodiment also makes it possible to facilitate the realization of the miniature and thin size of the first and second main pump bodies 12A, 12B, in the same manner as in the pump 10A according to the first embodiment. It is possible to make application to a variety of techniques including, for example, those concerning the medical field and the chemical analysis.

[0229] A modified embodiment 10Ea of the pump 10E according to the fifth embodiment may be constructed, for example, as shown in FIG. 44. That is, the intermediate support plate 160 is removed. The first and second input valve sections 18a, 18b are opposed to one another, the first and second pump sections 16a, 16b are opposed to one another, and the first and second output valve sections 20a, 20b are opposed to one another. Further, the respective end surfaces of the first and second displacement-transmitting sections 66a, 66b make mutual abutment.

[0230] In this embodiment, the first and second main pump bodies 12A, 12B may be supported with certain rigidity by using the unillustrated casing 14 and/or the unillustrated support pillars for supporting the casing 14. Alternatively, the first and second main pump bodies 12A, 12B may be supported with certain rigidity by using the casing 14 and/or the outer circumferential fixed section 14b for supporting the casing 14.

[0231] Next, a pump 10F according to a sixth embodiment is constructed as shown in FIG. 45. That is, two substrates 40, 162 are stacked with a spacer substrate 164 being interposed therebetween. The lower substrate 40 is installed with the input valve section 18 and the output valve section 20, and the upper substrate 162 is installed with the pump section 16.

[0232] The spacer substrate 164 includes the introducing hole 32 which is formed on the introduction side of the input valve section 18, and the discharge hole 34 which is formed on the discharge side of the output valve section 20. A substrate 162A of the upper substrate 162 includes a first through-hole 166 which is formed at a portion corresponding to the hollow space 44 of the pump section 16 and corresponding to the input valve section 18, and a second through-hole 168 which is formed at a portion corresponding to the hollow space 44 of the pump section 16 and corresponding to the output valve section 20.

[0233] The displacement action in the vertical direction of the actuator section 30 of the input valve section 18 allows a conical-shaped displacement-transmitting section 170 formed on the input valve section 18 to close and open the first through-hole 166. The displacement action in the vertical direction of the actuator section 30 of the output valve section 20 allows a conical-shaped displacement-transmitting section 172 formed on the output valve section 20 to close and open the second through-hole 168.

[0234] As a result, the fluid, which is introduced via the introducing hole 32, is introduced into the hollow space 44 of the pump section 16 by the aid of the input valve section 18. The volume of the hollow space 44 is changed in accordance with the displacement action in the vertical direction of the actuator section 30 of the pump section 16, and thus the fluid in the hollow space 44 is discharged via the output valve section 20 and the discharge hole 34.

[0235] The pump 10F according to the sixth embodiment also makes it possible to facilitate the realization of the miniature and thin size of the pump 10F, in the same manner as the pump 10A according to the first embodiment. It is possible to make application to a variety of techniques including, for example, those concerning the medical field and the chemical analysis.

[0236] The foregoing embodiments have been explained for the case in which the fluid is transported through the flow passage surrounded by the casing 14 and the displacement-transmitting section 66. Besides, as shown in FIG. 46, the present invention is also applicable to the transport of the fluid in the open system.

[0237] A pump 10G according to a seventh embodiment, which is applied to the open system, will be explained below with reference to FIGS. 46 to 47D.

[0238] The pump 10G according to the seventh embodiment includes a ceramic base 184 constructed such that a second substrate 182 comprising a second spacer layer 182B and a second thin plate layer 182C is stacked on a part of a first substrate 180 comprising a first substrate layer 180A, a first spacer layer 180B, and a first thin plate layer 180C.

[0239] A first actuator section 30a is formed on the second substrate 182 of the ceramic base 184. A second actuator section 30b is formed on a portion of the first substrate 180 in the vicinity of a step section disposed between the first substrate 180 and the second substrate 182.

[0240] A displacement-transmitting section 186, which is made of, for example, resin, is formed on the surface including the first and second actuator sections 30a, 30b. The upper surface of the displacement-transmitting section 186 is a tapered surface which is inclined along the difference in height of the ceramic base 184. Further, portions of the upper surface of the displacement-transmitting section 186, which correspond to the first and second actuator section 30a, 30b, are bulged upwardly respectively to construct a first dam section 188 and a second dam section 190. The ceramic base 184 and the displacement-transmitting section 186 are fixed and supported with certain rigidity by the aid of a casing 192 which is disposed on the side surface.

[0241] As shown in FIGS. 47A to 47D, the first and second dam sections 188, 190 have their heights which are set so that the bulges appear and disappear in accordance with the displacement action in the vertical direction of the first and second actuator sections 30a, 30b.

[0242] Next, explanation will be made with reference to FIGS. 47A to 47D for exemplary use of the pump 10G according to the seventh embodiment, for example, for exemplary use in which a certain amount of sample liquid 194 is successively transported.

[0243] At first, as shown in FIG. 47A, the sample liquid 194 is supplied at a stage in which the first and second dam sections 188, 190 are bulged. The sample liquid 194 is dammed by the first dam section 188 to cause no downward movement. Subsequently, as shown in FIG. 47B, when the first actuator section 30a for the first dam section 188 is displaced downwardly to disappear the bulge of the first dam section 188, the sample liquid 194, which has been dammed, moves toward the second dam section 190. The sample liquid 194 is dammed by the second dam section 190 to cause no downward movement.

[0244] Subsequently, as shown in FIG. 47C, when the first actuator section 30a for the first dam section 188 is displaced upwardly again to generate the bulge of the first dam section 188, the sample liquid 194 in an amount corresponding to the volume of the portion (amount-measuring section 196) comparted by the first dam section 188 and the second dam section 190 remains in the amount-measuring section 196. The overflow sample liquid flows over the second dam section 190, and it is recovered.

[0245] After that, as shown in FIG. 47D, when the second actuator section 30b for the second dam section 190 is displaced downwardly to disappear the bulge of the second dam section 190, the sample liquid 194, which has been pooled in the amount-measuring section 196, moves downwardly along the tapered surface of the displacement-transmitting section 186.

[0246] As described above, when the pump 10G according to the seventh embodiment is used, for example, a constant amount of the sample liquid 194 can be successively moved. Therefore, the pump 10G can be applied, for example, to an apparatus for quickly analyzing a trace amount of protein or gene. Thus, it is possible to make contribution to the research for novel drugs and the analysis of gene.

[0247] It is a matter of course that the pump according to the present invention is not limited to the embodiments described above, which may be embodied in other various forms without deviating from the gist or essential characteristics of the present invention.

Industrial Applicability

[0248] As described above, a pump according to the present invention can be of the compact and thin type, making it possible to increase the discharge amount (movement amount) of fluid. Further, it is possible to efficiently reduce the pressure on the introduction side and apply the pressure on the discharge side.

Claims

1. A pump comprising a main pump body including at least one pump section, for selectively forming a flow passage for a fluid in accordance with selective displacement action of said pump section in a direction to make approach or separation, wherein:

   said fluid is controlled for its flow in accordance with said selective formation of said flow passage in said main pump body.

2. The pump according to claim 1, wherein:

   said pump section includes at least one actuator section; and
   said actuator section comprises a shape-retaining layer, an operating section having at least one pair of electrodes formed on said shape-retaining layer, a vibrating section for supporting said operating section, and a fixed section for supporting said vibrating section in a vibrating manner.

3. The pump according to claim 2, wherein said pump section includes a displacement-transmitting section for transmitting said displacement action of said actuator section generated by applying a voltage to said pair of electrodes.

4. The pump according to claim 3, wherein a plurality of actuator sections are allotted corresponding to said displacement-transmitting section for said pump section.

5. The pump according to any one of claims 2 to 4, wherein at least said vibrating section, of said vibrating section and said fixed section, is composed of ceramics.

6. The pump according to any one of claims 2 to 5, wherein said vibrating section and said fixed section are formed in an integrated manner.

7. The pump according to any one of claims 2 to 6, wherein said vibrating section and said fixed section are formed of ceramics in an integrated manner.

8. The pump according to any one of claims 2 to 7, wherein said operating section for constructing said actuator section is formed in an integrated manner together with said vibrating section and said fixed section.

9. The pump according to any one of claims 2 to 8, wherein said shape-retaining layer is composed of a piezoelectric and/or electrostrictive layer and/or an anti-ferroelectric layer.

10. The pump according to any one of claims 2 to 9, wherein a hollow space for allowing said vibrating section to be capable of vibration is provided at a portion of said fixed section corresponding to said vibrating section, and a through-hole is formed to make penetration from a second principal surface of said fixed section to said hollow space.

11. The pump according to claim 10, wherein said through-hole is sealed.

12. The pump according to any one of claims 1 to 11, wherein said main pump body comprises a plurality of pump sections connected in series.

13. The pump according to claim 12, wherein when said pump sections, which are adjacent to one another and which are connected in series, are driven, said pump section disposed on a discharge side is driven once while said pump section disposed on an introduction side is driven in a plurality of times so that said flow of said fluid is controlled.

14. The pump according to any one of claims 1 to 13, wherein said main pump body is installed between an introduc-

tion side and a discharge side.

15. The pump according to claim 14, wherein a plurality of pump sections are connected in parallel on said introduction side.

16. The pump according to claim 14 or 15, wherein a plurality of pump sections are connected in parallel on said discharge side.

17. The pump according to any one of claims 14 to 16, wherein said main pump body comprises a plurality of pump sections connected in a branched configuration.

18. The pump according to any one of claims 14 to 17, wherein said main pump body comprises a plurality of pump sections connected in an arbitrary combination of series connection and parallel connection.

19. The pump according to any one of claims 1 to 18, wherein:

said pump section is provided opposingly to a part of a surface of a casing to which said fluid is supplied; and said main pump body is operated such that said flow passage for said fluid is selectively formed on said part of said surface of said casing in accordance with said selective displacement action of said pump section in said direction to make approach or separation with respect to said part of said surface of said casing.

20. The pump according to claim 19, wherein an end surface of a displacement-transmitting section contacts with said casing when said displacement of an actuator section of said pump section makes nearest approach to said casing.

21. The pump according to claim 19, wherein a gap is formed between an end surface of a displacement-transmitting section and said casing when said displacement of an actuator section of said pump section makes nearest approach to said casing.

22. The pump according to any one of claims 18 to 21, wherein said main pump body is supported with certain rigidity by at least said casing and/or a support pillar for supporting said casing.

23. The pump according to any one of claims 18 to 22, wherein said main pump body is supported with certain rigidity by at least said casing and/or an outer circumferential fixed section for supporting said casing.

24. The pump according to any one of claims 1 to 18, wherein:

a plurality of pump sections are installed opposingly to one another;
an intermediate support plate is provided between said pump sections; and
said main pump body selectively forms said flow passage for said fluid on a plate surface of said intermediate support plate in accordance with said selective displacement action of said pump sections in said direction to make approach or separation with respect to said plate surface of said intermediate support plate.

25. The pump according to claim 24, wherein said main pump body is supported with certain rigidity by at least said intermediate support plate and/or a support pillar for supporting said intermediate support plate.

26. The pump according to claim 24 or 25, wherein said main pump body is supported with certain rigidity by at least said intermediate support plate and/or an outer circumferential fixed section for supporting said intermediate support plate.

27. The pump according to any one of claims 1 to 18, wherein:

a plurality of pump sections are installed opposingly to one another; and
said main pump body selectively forms said flow passage for said fluid between said mutually opposing pump sections in accordance with said selective displacement action of said mutually opposing pump sections in said direction to make approach or separation.

28. The pump according to claim 27, further comprising:

a casing for supplying said fluid thereto, wherein:

said main pump body is supported with certain rigidity by at least said casing and/or a support pillar for supporting said casing.

29. The pump according to claim 27 or 28, further comprising:

a casing for supplying said fluid thereto, wherein:
said main pump body is supported with certain rigidity by at least said casing and/or an outer circumferential fixed section for supporting said casing.

30. The pump according to any one of claims 1 to 29, wherein:

a plurality of pump sections are provided; and
a valve section is allowed to intervene between said pump sections.

31. The pump according to claim 30, wherein:

said plurality of pump sections are provided; and
a set comprising said valve section disposed between said pump sections, and a set comprising no valve section disposed between said pump sections are arbitrarily combined.

32. The pump according to claim 30 or 31, wherein:

said valve section comprises at least one valve actuator section provided opposingly to a part of a surface of a casing to which said fluid is supplied; and
said flow of said fluid from said pump section disposed at an upstream stage to said pump section disposed at a downstream stage is controlled in accordance with said displacement action of said valve actuator section in said direction to make approach or separation with respect to said part of said surface of said casing.

33. The pump according to claim 30 or 31, wherein:

a plurality of valve sections are installed opposingly to one another;
an intermediate support plate is provided between said valve sections;
each of said valve sections comprises at least one valve actuator section provided opposingly to a plate surface of said intermediate support plate; and
said flow of said fluid from said pump section disposed at an upstream stage to said pump section disposed at a downstream stage is controlled in accordance with said displacement action of said valve actuator section in said direction to make approach or separation with respect to said plate surface of said intermediate support plate.

34. The pump according to claim 30 or 31, wherein:

a plurality of valve sections are installed opposingly to one another;
each of said valve sections comprises at least one valve actuator section provided opposingly to one another; and
said flow of said fluid from said pump section disposed at an upstream stage to said pump section disposed at a downstream stage is controlled in accordance with said displacement action of said mutually opposing valve actuator section in said direction to make approach or separation.

35. The pump according to any one of claims 32 to 34, wherein said plurality of valve actuator sections are allotted corresponding to a displacement-transmitting section for said valve section.

36. The pump according to any one of claims 32 to 35, wherein a displacement-transmitting section for an actuator section of said pump section is formed continuously with a displacement-transmitting section for said actuator section of said valve section.

37. The pump according to claim 36, wherein a crosstalk-preventive section is formed between said displacement-transmitting section for said actuator section of said pump section and said displacement-transmitting section for said actuator section of said valve section.

38. The pump according to any one of claims 32 to 37, wherein a vibrating section and a fixed section of an actuator section of said pump section and a vibrating section and a fixed section of said actuator section of said valve section are integrally formed of ceramics.

39. The pump according to any one of claims 30 to 38, wherein at least one of said valve sections has a shape of check valve.

40. The pump according to any one of claims 1 to 39, further comprising at least one input valve section disposed on an introduction side of said pump section.

41. The pump according to claim 40, wherein said input valve section comprises at least one input valve actuator section provided opposingly to a part of a surface of a casing to which said fluid is supplied; and

said flow of said fluid from said pump section disposed at an upstream stage to said pump section disposed at a downstream stage is controlled in accordance with said displacement action of said input valve actuator section in said direction to make approach or separation with respect to said part of said surface of said casing.

42. The pump according to claim 40, wherein:

a plurality of input valve sections are installed opposingly to one another;
an intermediate support plate is provided between said input valve sections;
each of said input valve sections comprises at least one input valve actuator section provided opposingly to a plate surface of said intermediate support plate; and
said flow of said fluid from said pump section disposed at an upstream stage to said pump section disposed at a downstream stage is controlled in accordance with said displacement action of said input valve actuator section in said direction to make approach or separation with respect to said plate surface of said intermediate support plate.

43. The pump according to claim 40, wherein:

a plurality of input valve sections are installed opposingly to one another;
each of said input valve sections comprises at least one input valve actuator section provided opposingly to one another; and
said flow of said fluid from said pump section disposed at an upstream stage to said pump section disposed at a downstream stage is controlled in accordance with said displacement action of said mutually opposing input valve actuator sections in said direction to make approach or separation.

44. The pump according to any one of claims 41 to 43, wherein said plurality of input valve actuator sections are allotted corresponding to a displacement-transmitting section for said input valve section.

45. The pump according to any one of claims 41 to 44, wherein a displacement-transmitting section for an actuator section of said pump section is formed continuously with a displacement-transmitting section for said actuator section of said input valve section.

46. The pump according to claim 45, wherein a crosstalk-preventive section is formed between said displacement-transmitting section for said actuator section of said pump section and said displacement-transmitting section for said actuator section of said input valve section.

47. The pump according to any one of claims 41 to 46, wherein a vibrating section and a fixed section of an actuator section for said pump section and a vibrating section and a fixed section for said actuator section of said input valve section are integrally formed of ceramics.

48. The pump according to any one of claims 40 to 47, wherein at least one of said input valve sections has a shape of check valve.

49. The pump according to any one of claims 1 to 48, further comprising at least one output valve section disposed on a discharge side of said pump section.

50. The pump according to claim 49, wherein said output valve section comprises at least one output valve actuator section provided opposingly to a part of a surface of a casing to which said fluid is supplied; and

said flow of said fluid from said pump section disposed at an upstream stage to said pump section disposed at a downstream stage is controlled in accordance with said displacement action of said output valve actuator section in said direction to make approach or separation with respect to said part of said surface of said casing.

51. The pump according to claim 49, wherein:

a plurality of output valve sections are installed opposingly to one another;
an intermediate support plate is provided between said output valve sections;
each of said output valve sections comprises at least one output valve actuator section provided opposingly to a plate surface of said intermediate support plate; and
said flow of said fluid from said pump section disposed at an upstream stage to said pump section disposed at a downstream stage is controlled in accordance with said displacement action of said output valve actuator section in said direction to make approach or separation with respect to said plate surface of said intermediate support plate.

52. The pump according to claim 49, wherein: a plurality of output valve sections are installed opposingly to one another;

each of said output valve sections comprises at least one output valve actuator section provided opposingly to one another; and
said flow of said fluid from said pump section disposed at an upstream stage to said pump section disposed at a downstream stage is controlled in accordance with said displacement action of said mutually opposing output valve actuator sections in said direction to make approach or separation.

53. The pump according to any one of claims 50 to 52, wherein said plurality of output valve actuator sections are allotted corresponding to a displacement-transmitting section for said output valve section.

54. The pump according to any one of claims 50 to 53, wherein a displacement-transmitting section for an actuator section of said pump section is formed continuously with a displacement-transmitting section for said actuator section of said output valve section.

55. The pump according to claim 54, wherein a crosstalk-preventive section is formed between said displacement-transmitting section for said actuator section of said pump section and said displacement-transmitting section for said actuator section of said output valve section.

56. The pump according to any one of claims 50 to 55, wherein a vibrating section and a fixed section of an actuator section of said pump section and a vibrating section and a fixed section of said actuator section of said output valve section are integrally formed of ceramics.

57. The pump according to any one of claims 49 to 56, wherein at least one of said output valve sections has a shape of check valve.

58. A pump comprising a main pump body including at least one input valve section, at least one pump section, and at least one output valve section, for selectively forming a flow passage for a fluid in accordance with selective displacement action of said input valve section, said pump section, and said output valve section in a direction to make approach or separation, wherein:

said fluid is controlled for its flow in accordance with said selective formation of said flow passage in said main pump body.

59. The pump according to claim 58, wherein:

said input valve section, said pump section, and said output valve section are provided opposingly to a part of a surface of a casing to which said fluid is supplied; and

said main pump body is operated such that said flow passage for said fluid is selectively formed on said part of said surface of said casing in accordance with said selective displacement action of said input valve section, said pump section, and said output valve section in said direction to make approach or separation with respect to said part of said surface of said casing.

60. The pump according to claim 58, wherein:

a plurality of input valve sections, a plurality of pump sections, and a plurality of output valve sections are installed opposingly to one another;
an intermediate support plate is provided between said input valve sections, between said pump sections, and between said output valve sections; and
said main pump body is operated such that said flow passage for said fluid is selectively formed on a plate surface of said intermediate support plate in accordance with said selective displacement action of said input valve sections, said pump sections, and said output valve sections in said direction to make approach or separation with respect to said plate surface of said intermediate support plate.

61. The pump according to claim 58, wherein:

a plurality of input valve sections, a plurality of pump sections, and a plurality of output valve sections are installed opposingly to one another; and
said main pump body is operated such that said flow passage for said fluid is selectively formed between said input valve sections, said pump sections, and said output valve sections which are opposed to one another in accordance with said selective displacement action of said input valve sections, said pump sections, and said output valve sections which are opposed to one another, in said direction to make approach or separation.

62. The pump according to any one of claims 58 to 61, wherein said flow passage is formed when both of said input valve section and said pump section which are adjacent to one another are operated, when both of said pump sections which are adjacent to one another are operated, or when both of said pump section and said output valve section which are adjacent to one another are operated.

63. The pump according to any one of claims 58 to 62, wherein a communication passage is formed to make a bypass between said flow passage formed between said input valve section and said pump section which are adjacent to one another and said flow passage formed between said pump sections which are adjacent to one another, and make a bypass between said flow passage formed between said pump sections which are adjacent to one another and said flow passage formed between said pump section and said output valve section which are adjacent to one another.

64. A pump comprising a main pump body including at least one input valve section, a plurality of pump sections, at least one valve section installed between said plurality of pump sections, and at least one output valve section, for selectively forming a flow passage for a fluid in accordance with selective displacement action of said input valve section, said pump sections, said valve section, and said output valve section in a direction to make approach or separation, wherein:

said fluid is controlled for its flow in accordance with said selective formation of said flow passage in said main pump body.

65. The pump according to claim 64, wherein:

said input valve section, said pump sections, said valve section, and said output valve section are provided opposingly to a part of a surface of a casing to which said fluid is supplied; and
said main pump body is operated such that said flow passage for said fluid is selectively formed on said part of said surface of said casing in accordance with said selective displacement action of said input valve section, said pump sections, said valve section, and said output valve section in said direction to make approach or separation with respect to said part of said surface of said casing.

66. The pump according to claim 64, wherein:

a plurality of input valve sections, a plurality of pump sections, a plurality of valve sections, and a plurality of output valve sections are installed opposingly to one another;

an intermediate support plate is provided between said input valve sections, between said pump sections, between said valve sections, and between said output valve sections; and

said main pump body is operated such that said flow passage for said fluid is selectively formed on a plate surface of said intermediate support plate in accordance with said selective displacement action of said input valve sections, said pump sections, said valve sections, and said output valve sections in said direction to make approach or separation with respect to said plate surface of said intermediate support plate.

67. The pump according to claim 64, wherein:

a plurality of input valve sections, a plurality of pump sections, a plurality of valve sections, and a plurality of output valve sections are installed opposingly to one another; and

said main pump body is operated such that said flow passage for said fluid is selectively formed between said input valve sections, said pump sections, said valve sections, and said output valve sections which are opposed to one another in accordance with said selective displacement action of said input valve sections, said pump sections, said valve sections, and said output valve sections which are opposed to one another, in said direction to make approach or separation.

68. The pump according to any one of claims 64 to 67, wherein said flow passage is formed when both of said input valve section and said pump section which are adjacent to one another are operated, when both of said pump section and said valve section which are adjacent to one another are operated, or when both of said pump section and said output valve section which are adjacent to one another are operated.

69. The pump according to any one of claims 64 to 68, wherein a communication passage is formed to make a bypass between said flow passage formed between said input valve section and said pump section which are adjacent to one another and said flow passage formed between said pump sections which are adjacent to one another, and make a bypass between said flow passage formed between said pump sections which are adjacent to one another and said flow passage formed between said pump section and said output valve section which are adjacent to one another.

70. A pump comprising a main pump body including at least one input valve section, a plurality of pump sections some of which belong to a set including a valve section intervening between said pump sections that are adjacent to one another and the other of which belong to a set including no valve section intervening between said pump sections that are adjacent to one another, and at least one output valve section, for selectively forming a flow passage for a fluid in accordance with selective displacement action of said input valve section, said pump sections, said valve section, and said output valve section in a direction to make approach or separation, wherein:

said fluid is controlled for its flow in accordance with said selective formation of said flow passage in said main pump body.

71. The pump according to claim 70, wherein:

said input valve section, said pump sections, said valve section, and said output valve section are provided opposingly to a part of a surface of a casing to which said fluid is supplied; and

said main pump body is operated such that said flow passage for said fluid is selectively formed on said part of said surface of said casing in accordance with said selective displacement action of said input valve section, said pump sections, said valve section, and said output valve section in said direction to make approach or separation with respect to said part of said surface of said casing.

72. The pump according to claim 70, wherein:

a plurality of input valve sections, a plurality of pump sections, a plurality of valve sections, and a plurality of output valve sections are installed opposingly to one another;

an intermediate support plate is provided between said input valve sections, between said pump sections, between said valve sections, and between said output valve sections; and

said main pump body is operated such that said flow passage for said fluid is selectively formed on a plate surface of said intermediate support plate in accordance with said selective displacement action of said input valve sections, said pump sections, said valve sections, and said output valve sections in said direction to make approach or separation with respect to said plate surface of said intermediate support plate.

73. The pump according to claim 70, wherein:

a plurality of input valve sections, a plurality of pump sections, a plurality of valve sections, and a plurality of output valve sections are installed opposingly to one another; and
said main pump body is operated such that said flow passage for said fluid is selectively formed between said input valve sections, said pump sections, said valve sections, and said output valve sections which are opposed to one another in accordance with said selective displacement action of said input valve sections, said pump sections, said valve sections, and said output valve sections which are opposed to one another, in said direction to make approach or separation.

74. The pump according to any one of claims 70 to 73, wherein said flow passage is formed when both of said input valve section and said pump section which are adjacent to one another are operated, when both of said pump section and said valve section which are adjacent to one another are operated, or when both of said pump section and said output valve section which are adjacent to one another are operated.

75. The pump according to any one of claims 70 to 74, wherein a communication passage is formed to make a bypass between said flow passage formed between said input valve section and said pump section which are adjacent to one another and said flow passage formed between said pump sections which are adjacent to one another, and make a bypass between said flow passage formed between said pump sections which are adjacent to one another and said flow passage formed between said pump section and said output valve section which are adjacent to one another.

FIG. 1

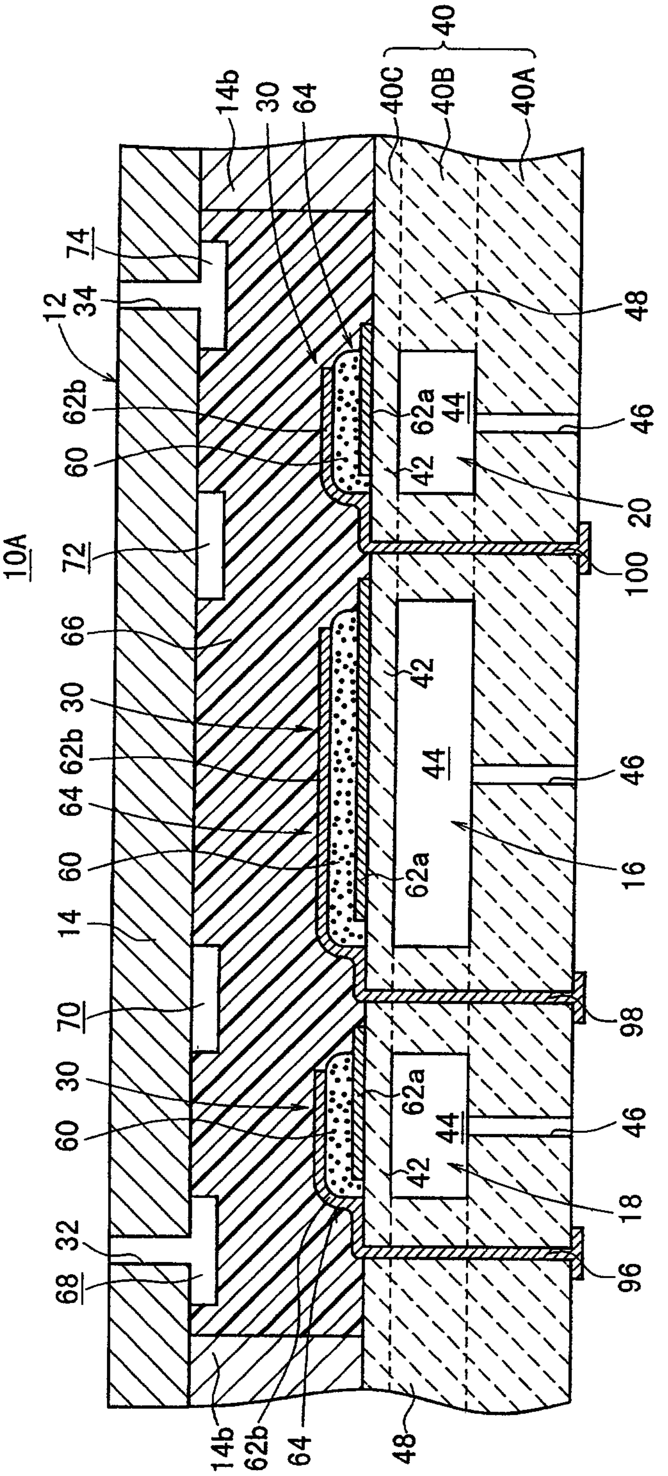

10A
12
14
14b
30
32
34
40
40A
40B
40C
42
44
46
48
60
62a
62b
64
66
68
70
72
74
16
18
20
96
98
100

FIG. 2

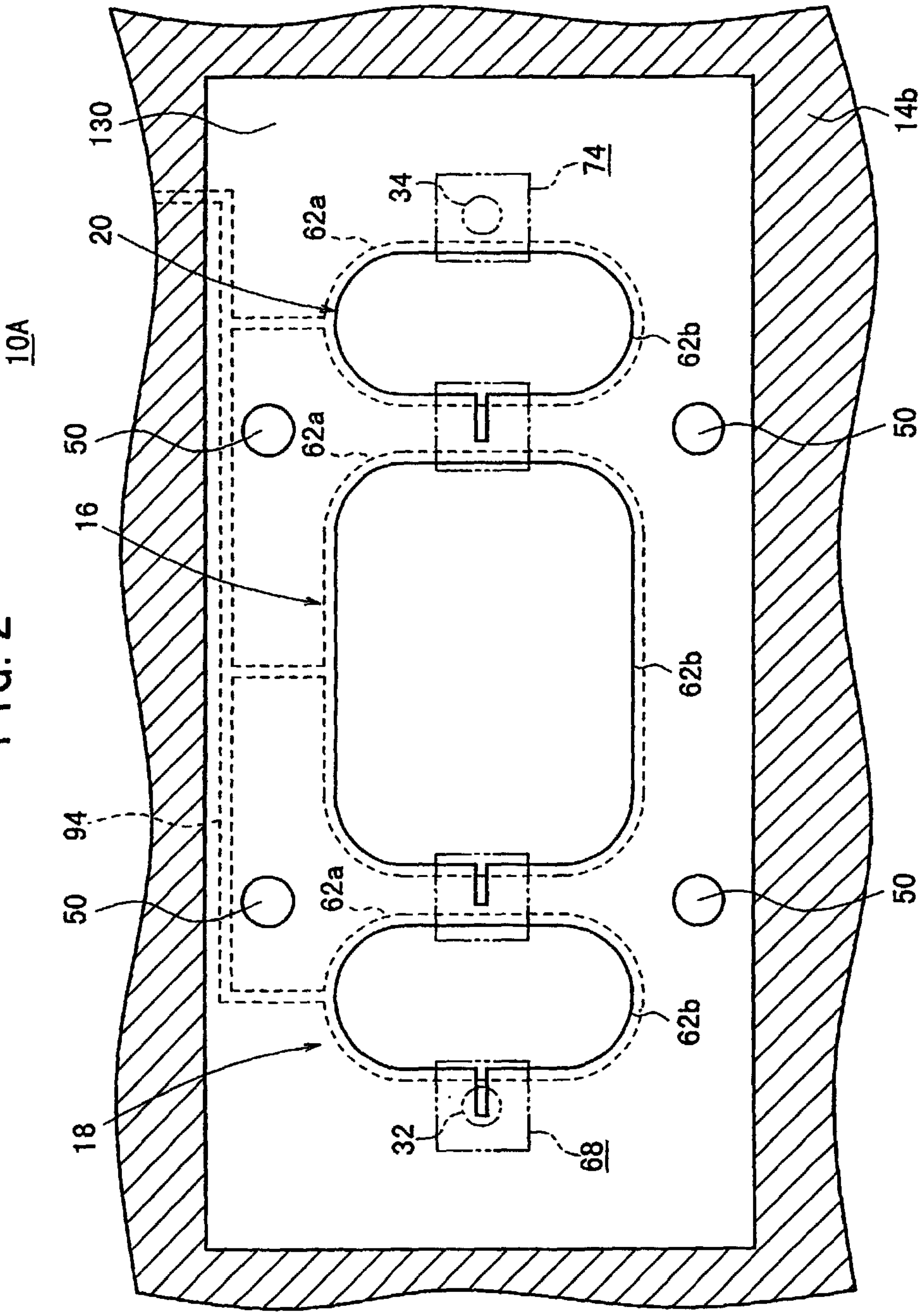

10A
130
14b
74
34
20
62a
62b
50
62a
16
62b
94
50
62a
50
50
62b
18
32
68

FIG. 3

10A

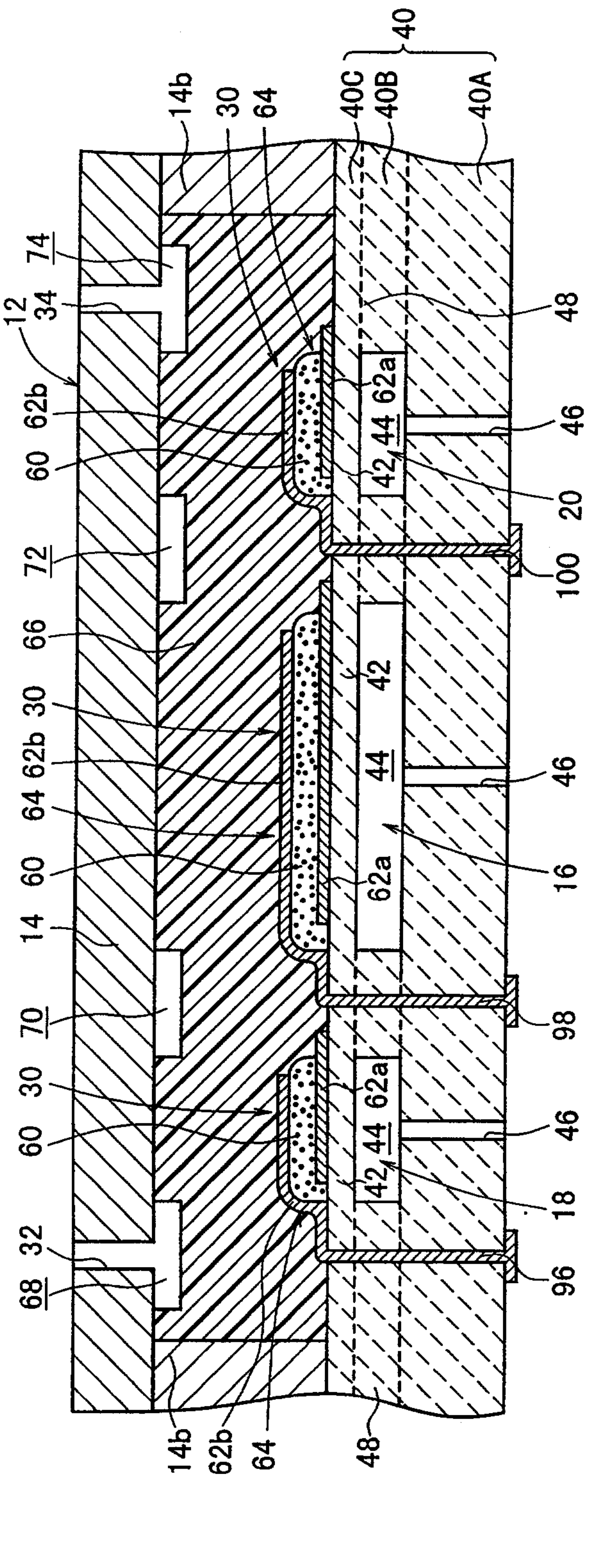

40
40C
40B
40A
14b
30
64
74
34
12
62b
60
72
66
30
62b
64
60
14
70
30
60
32
68
48
62a
44
42
46
20
100
42
44
46
16
62a
98
62a
44
42
46
18
96
14b
62b
64
48

FIG. 4

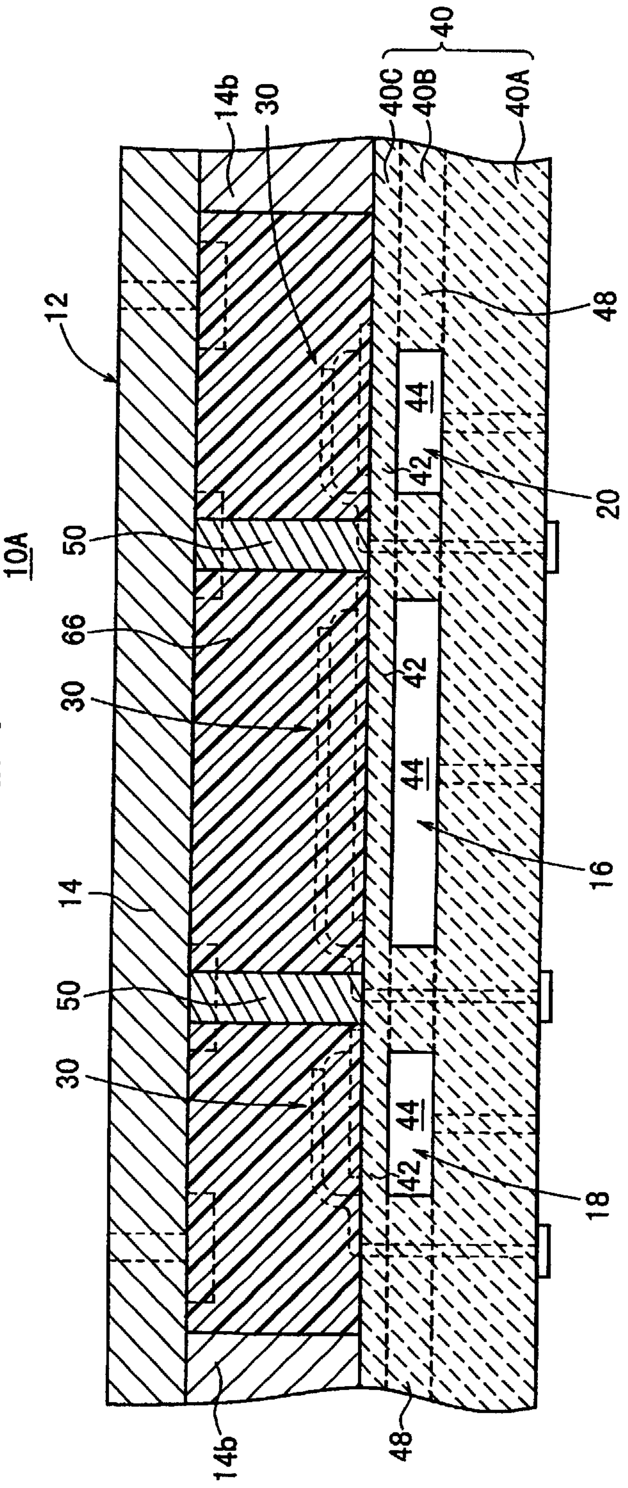


FIG. 5

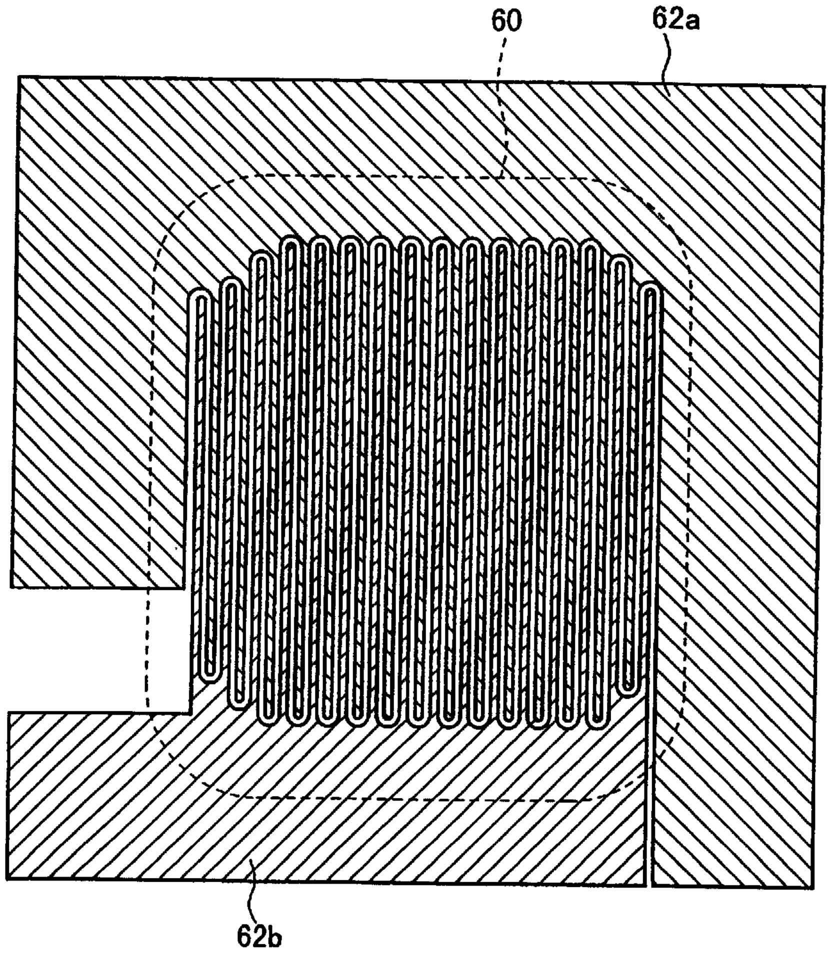


FIG. 6A

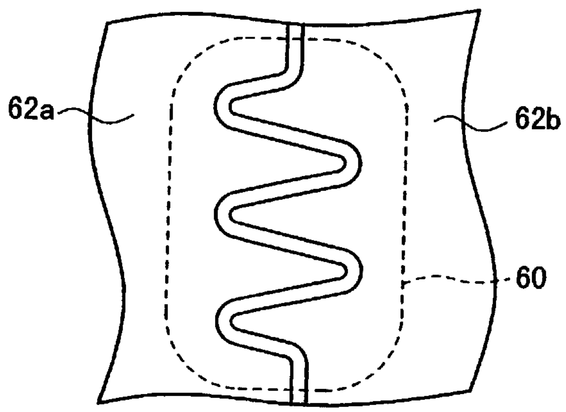


FIG. 6B

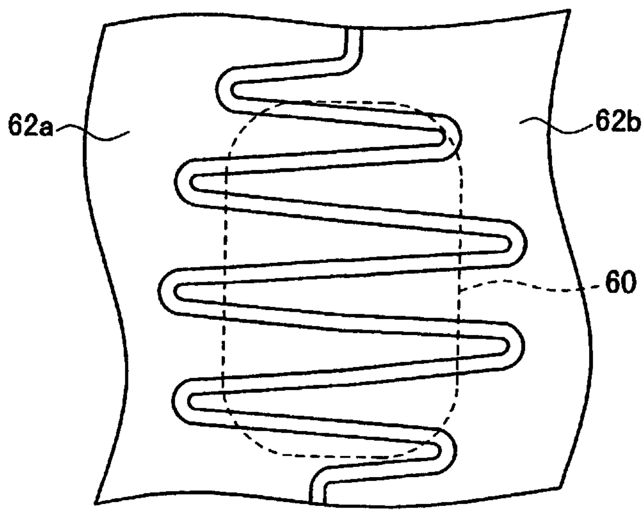


FIG. 7A

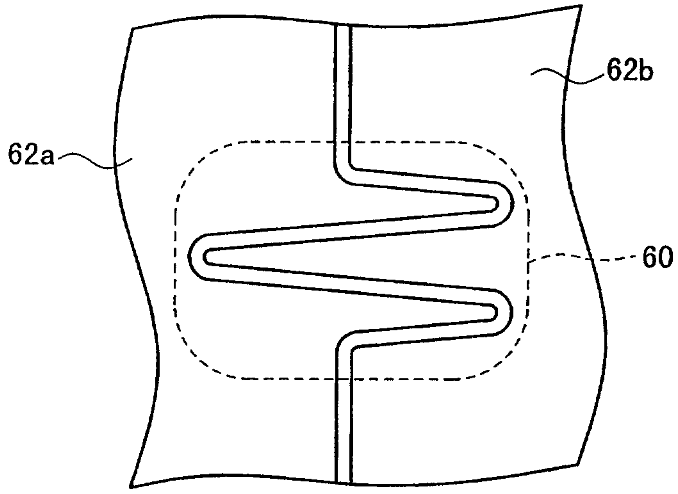


FIG. 7B

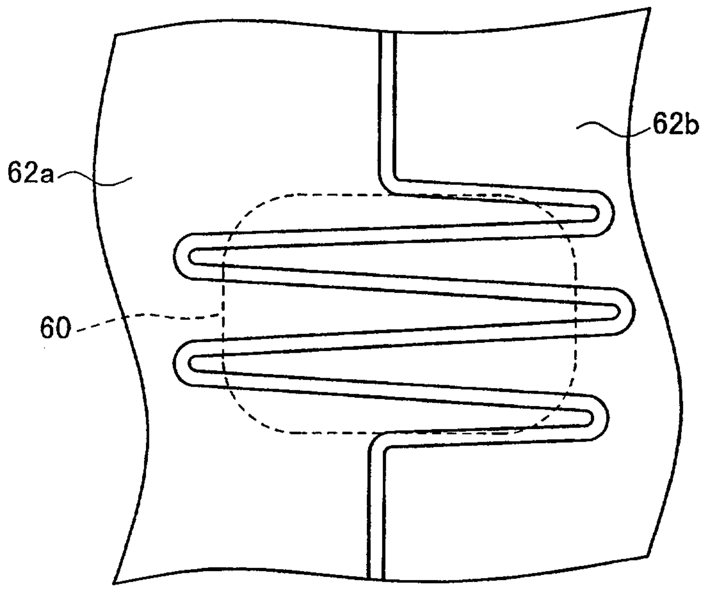


FIG. 8

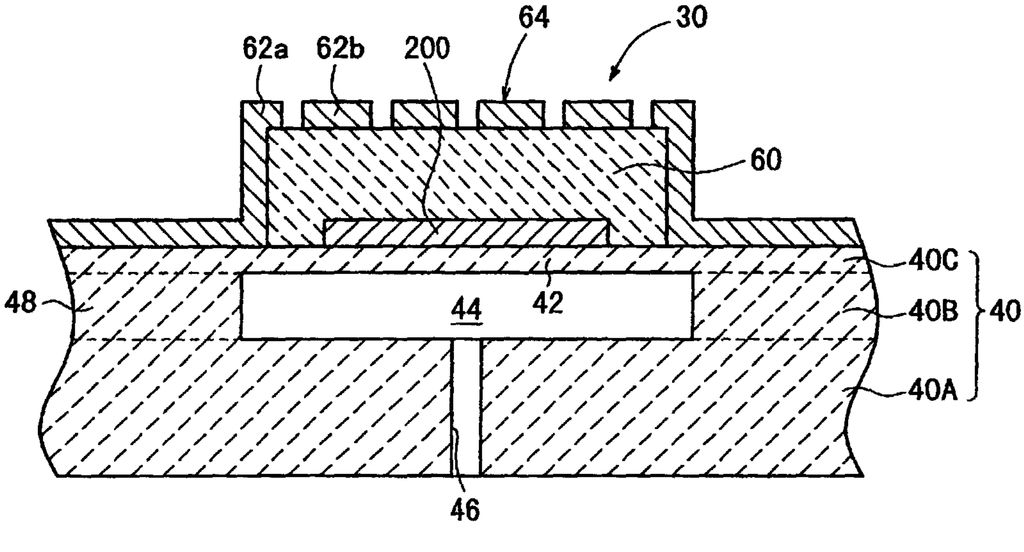


FIG. 9

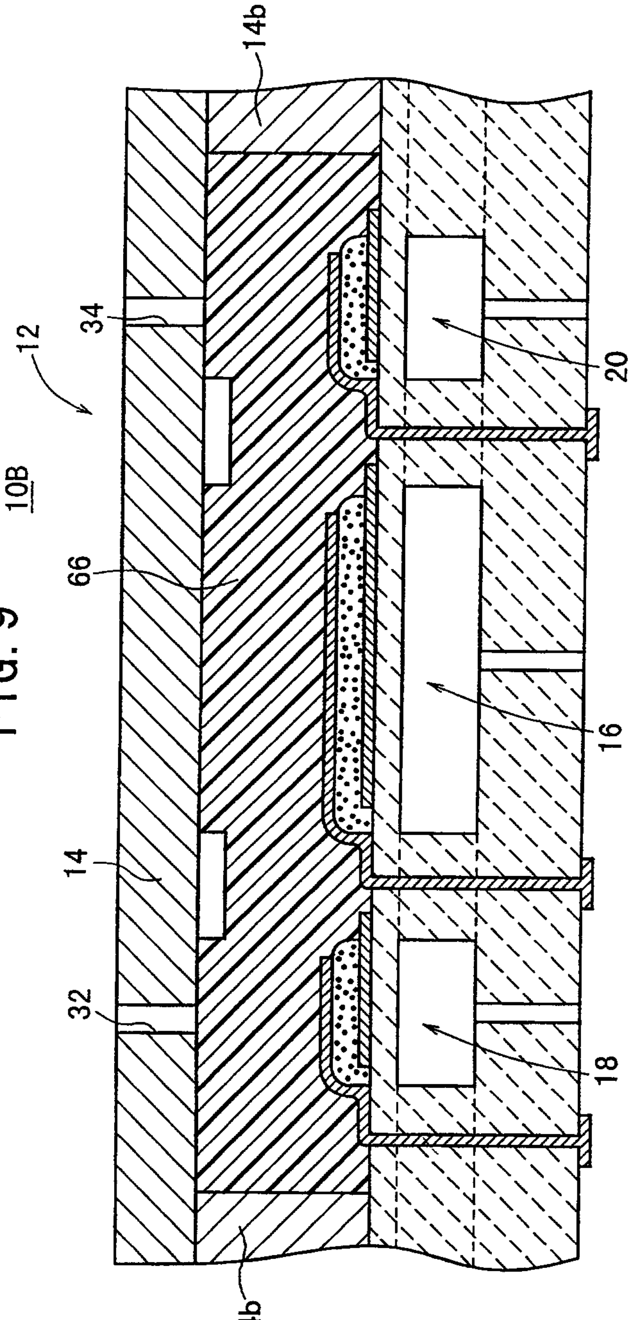


FIG. 10

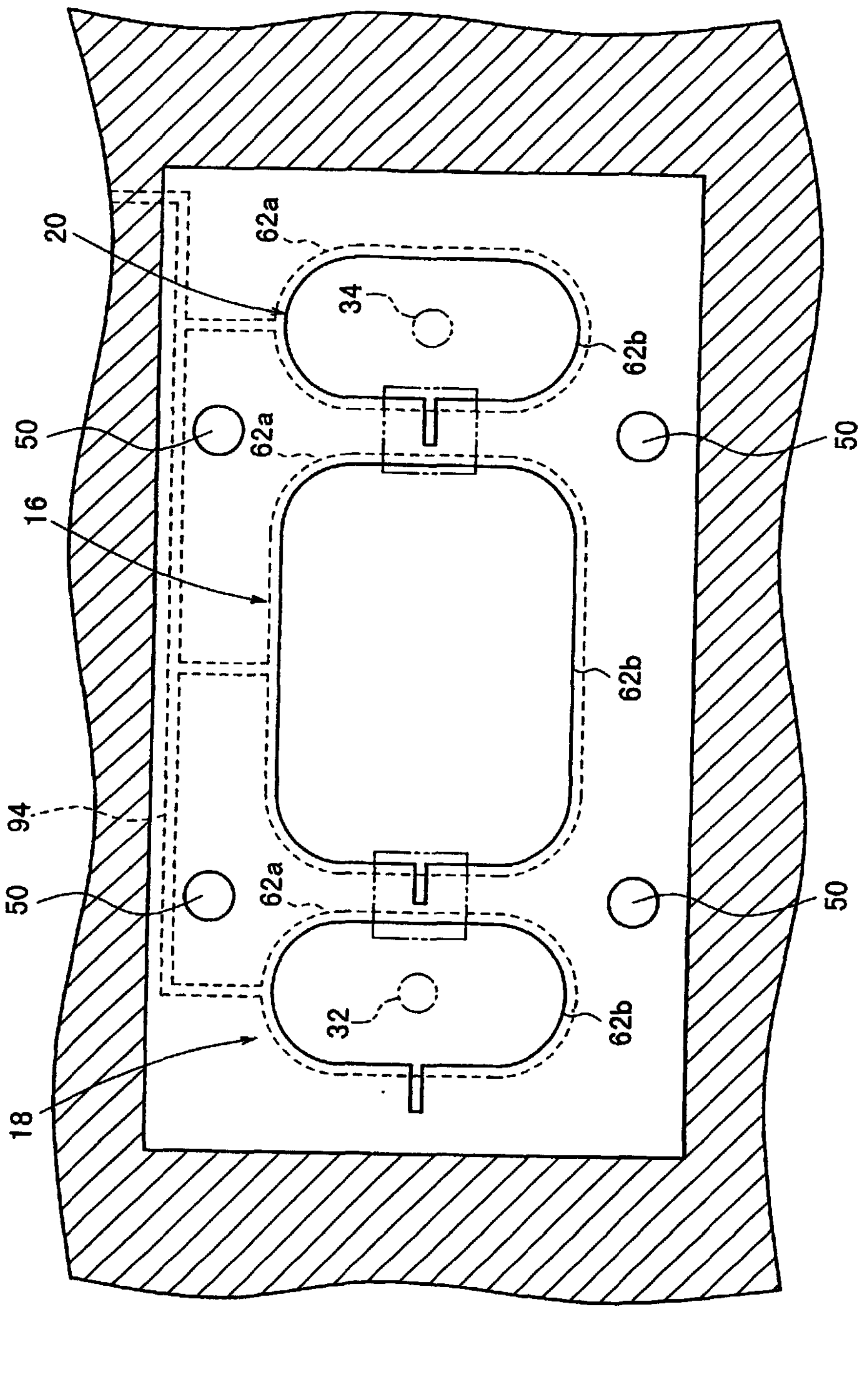


FIG. 11

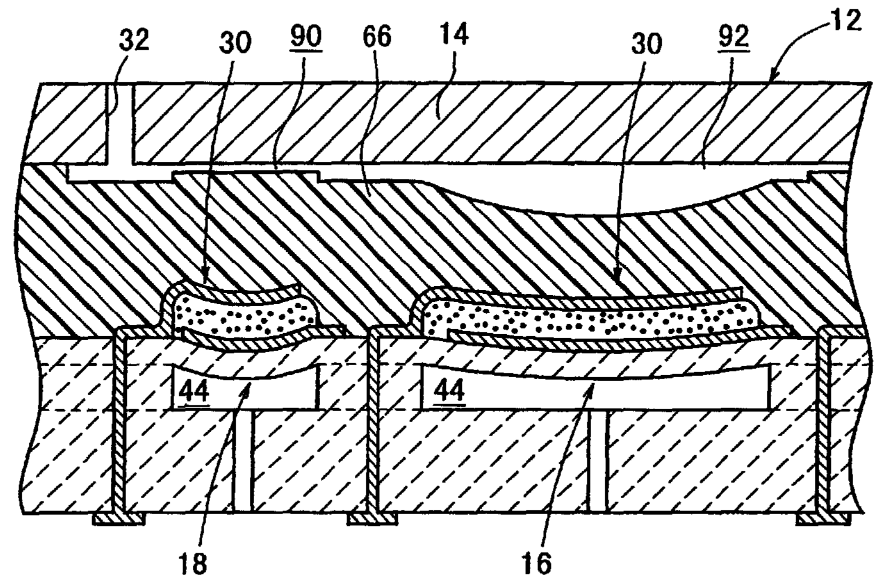


FIG. 12A

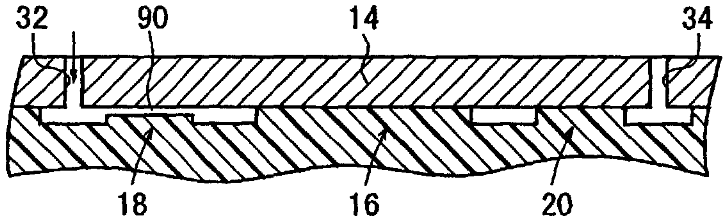


FIG. 12B

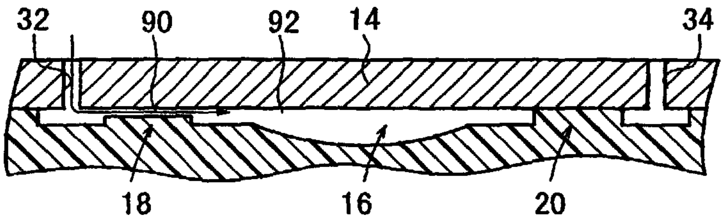


FIG. 12C

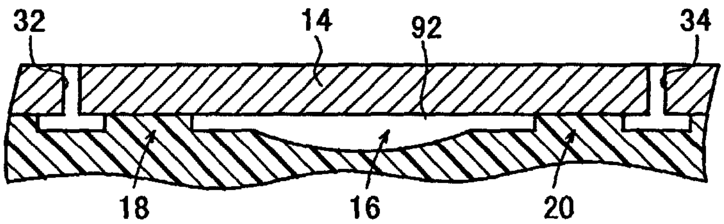


FIG. 12D

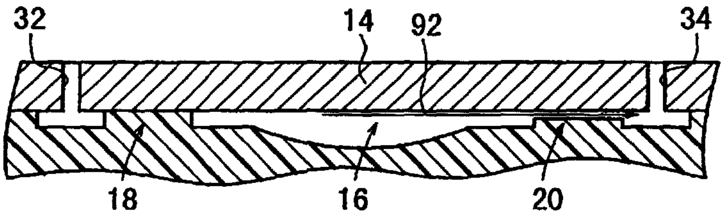


FIG. 12E

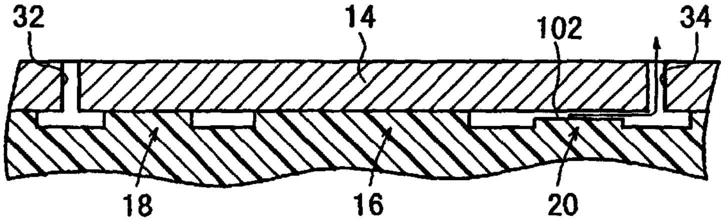


FIG. 12F

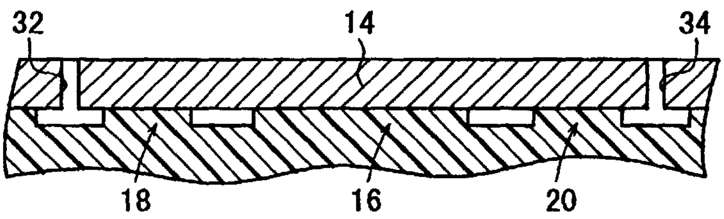


FIG. 13

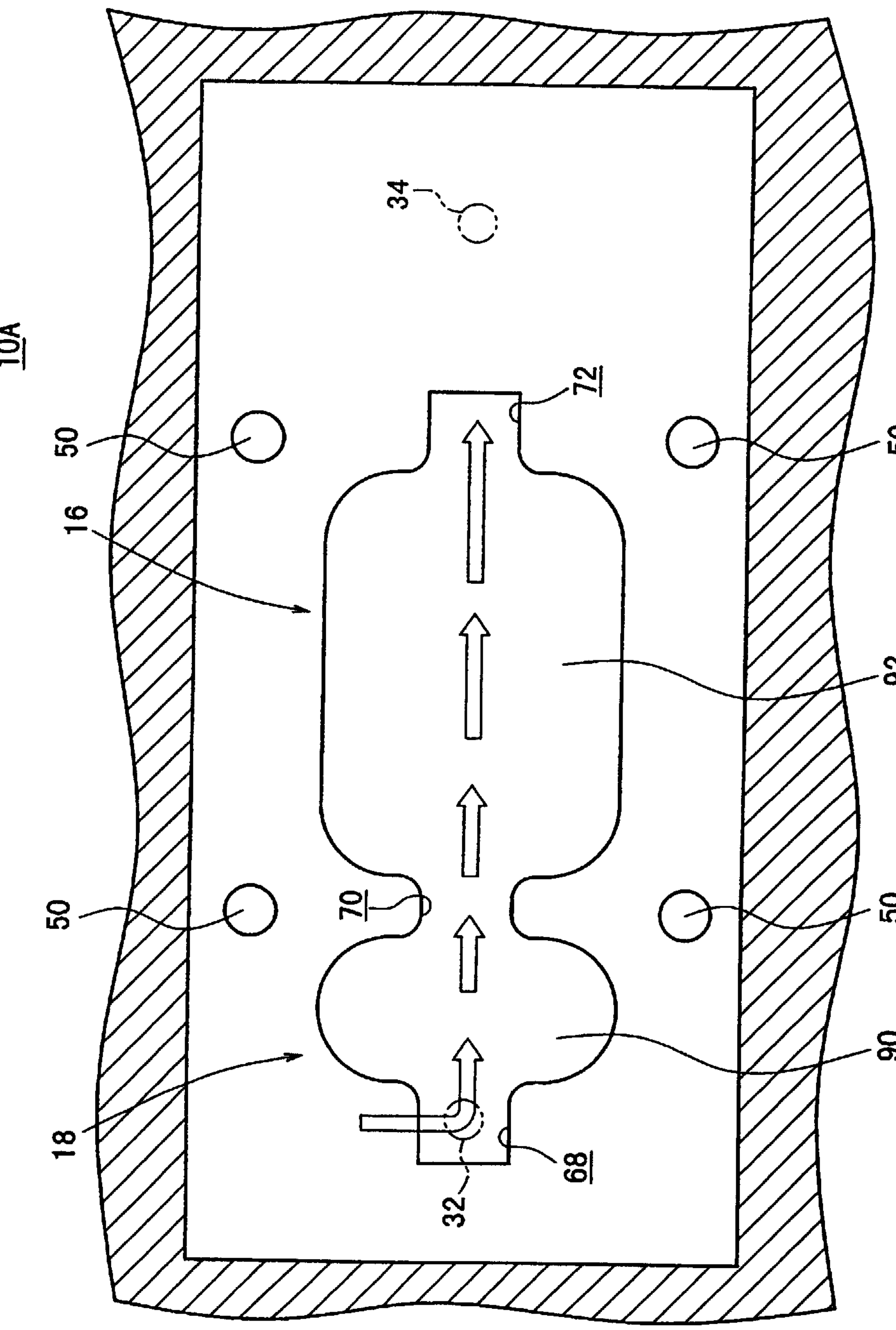


FIG. 14

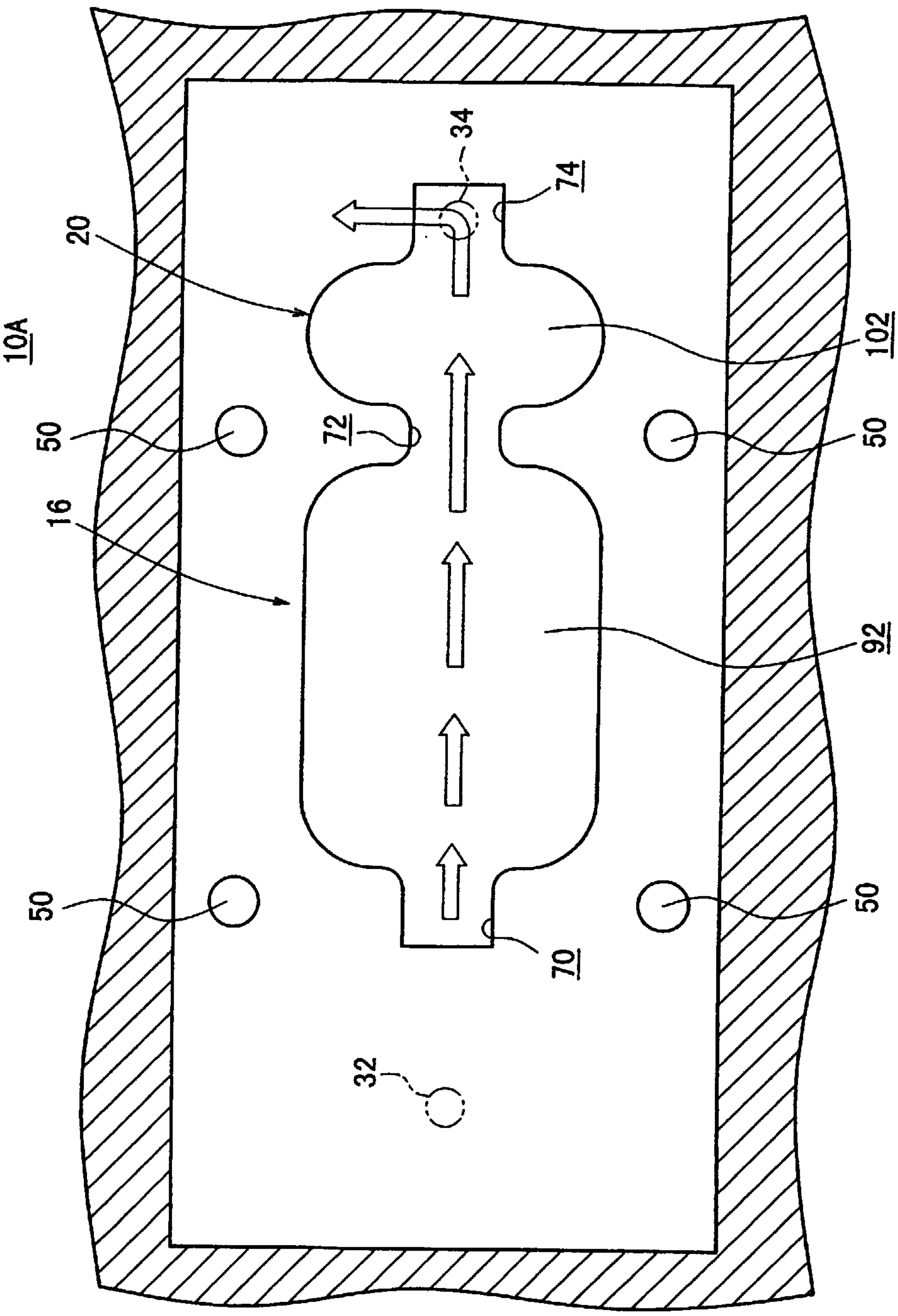


FIG. 15

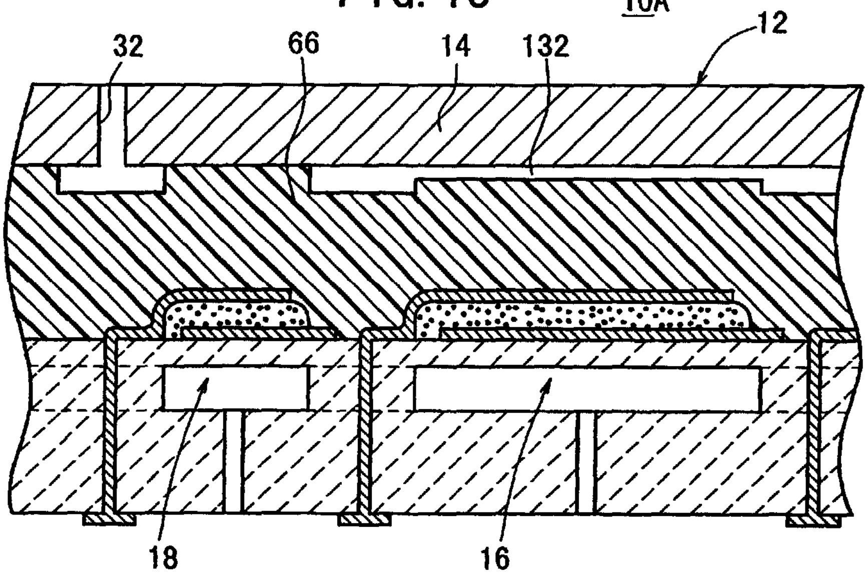


FIG. 16

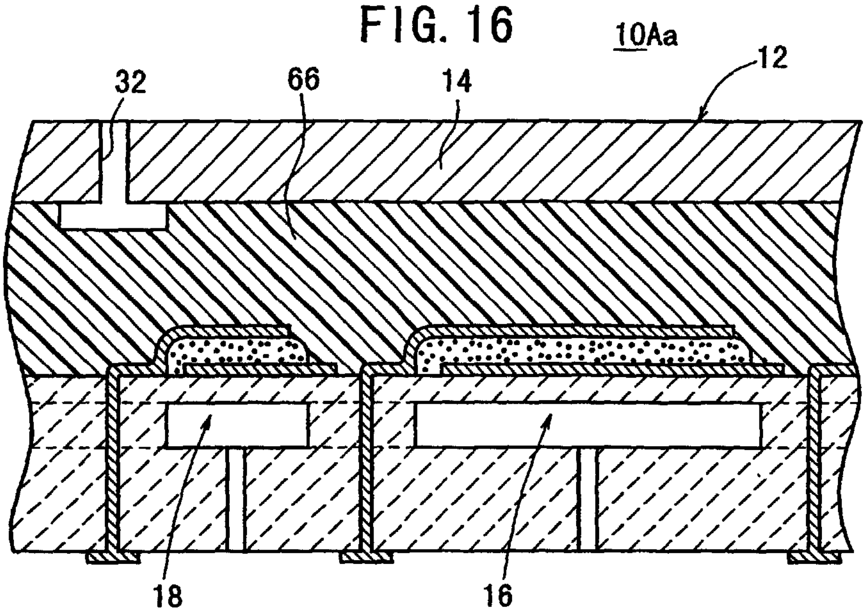


FIG. 17

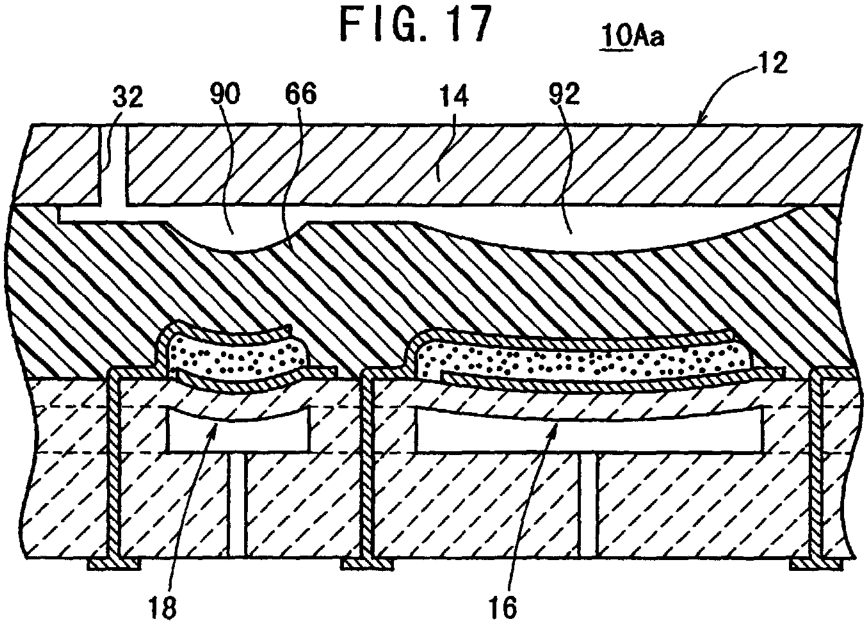


FIG. 18

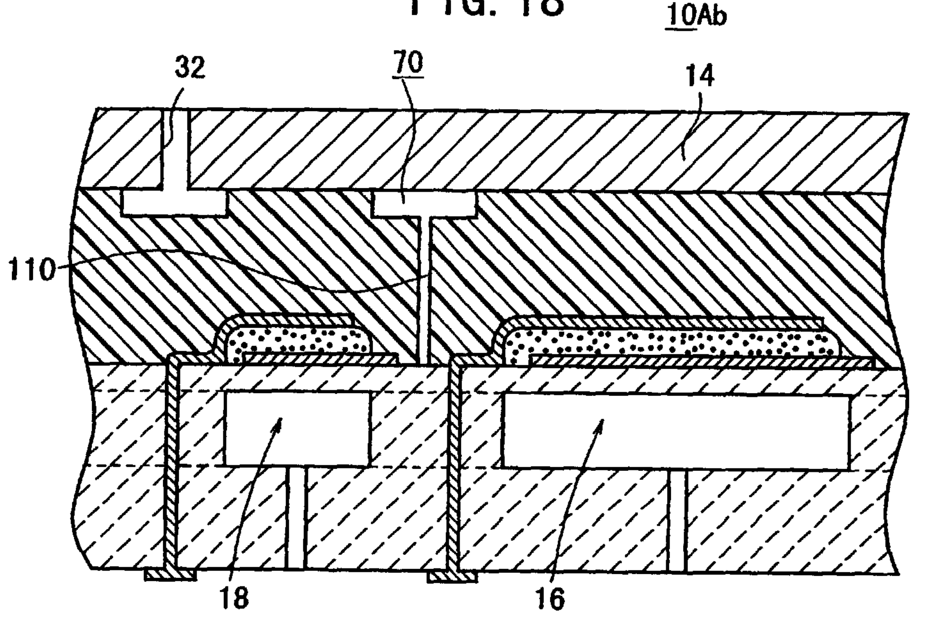


FIG. 19

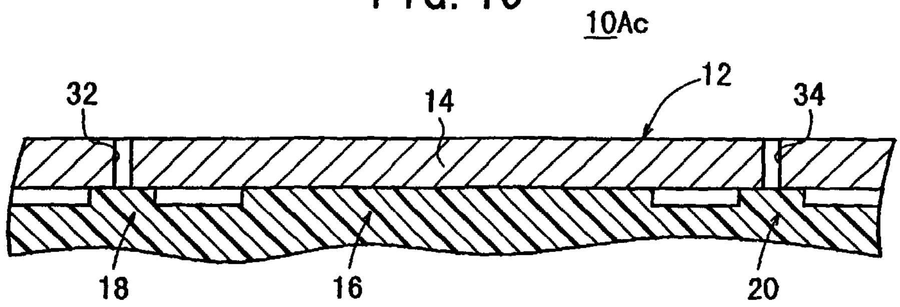


FIG. 20

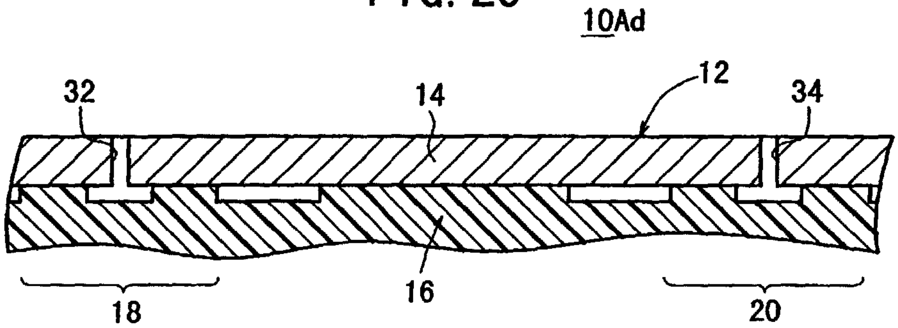


FIG. 21

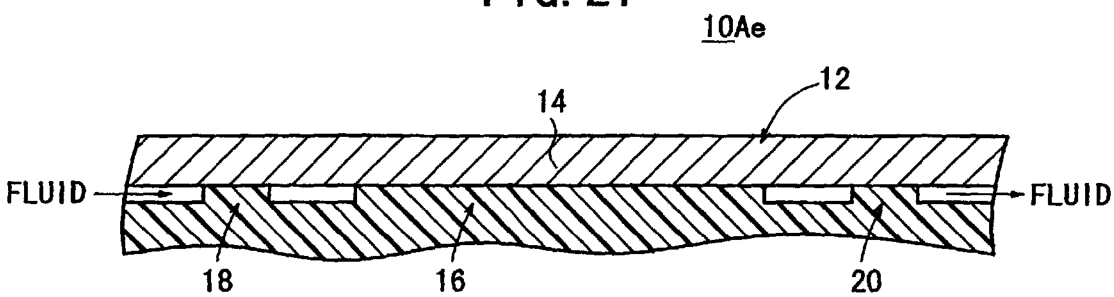


FIG. 22

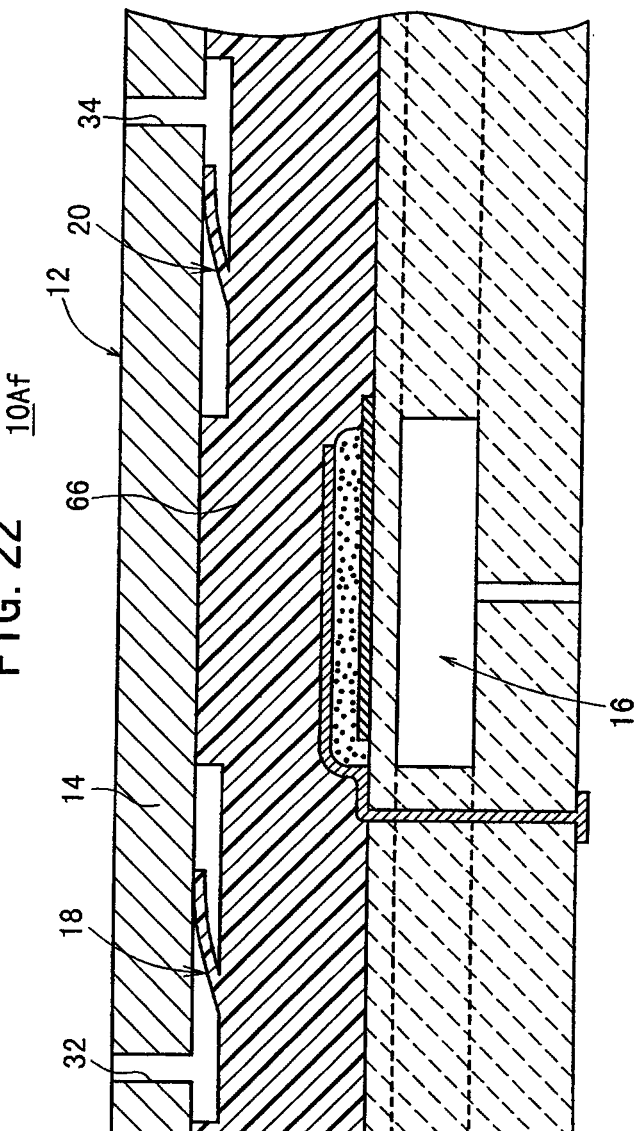
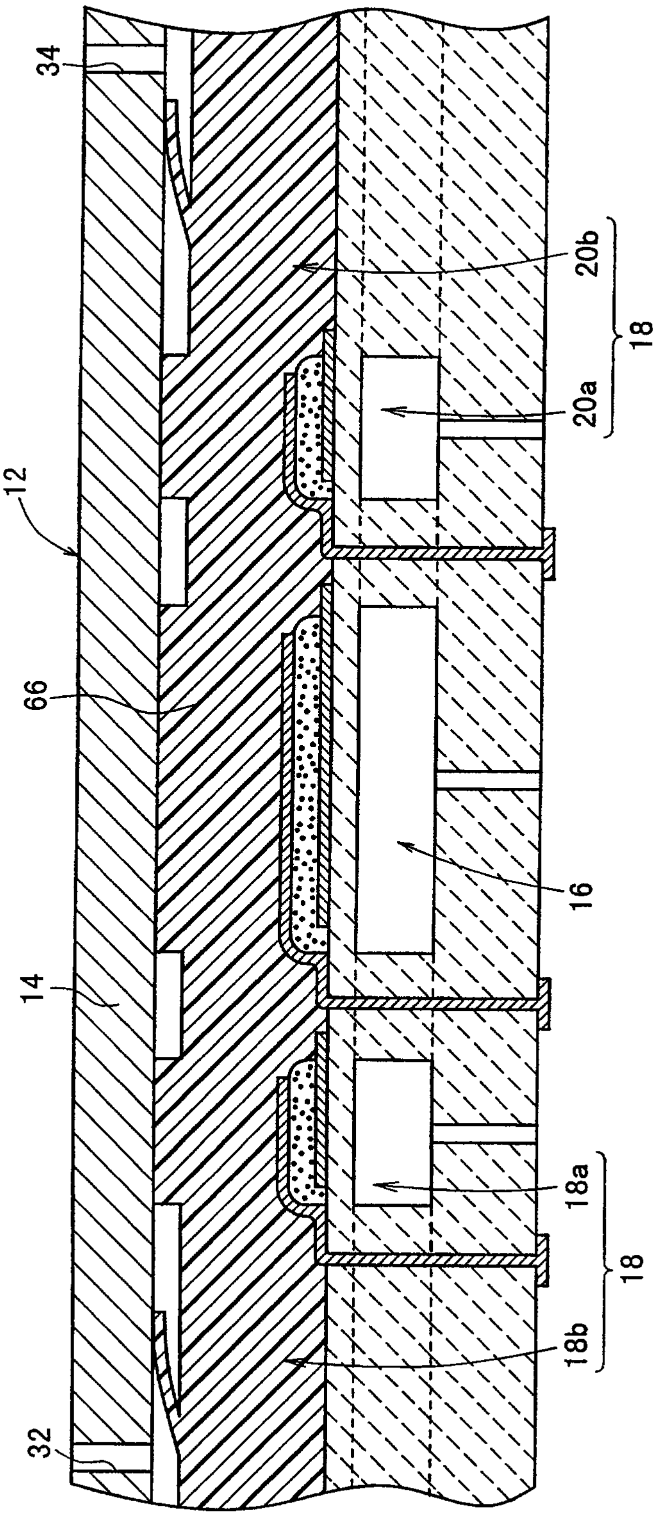


FIG. 23



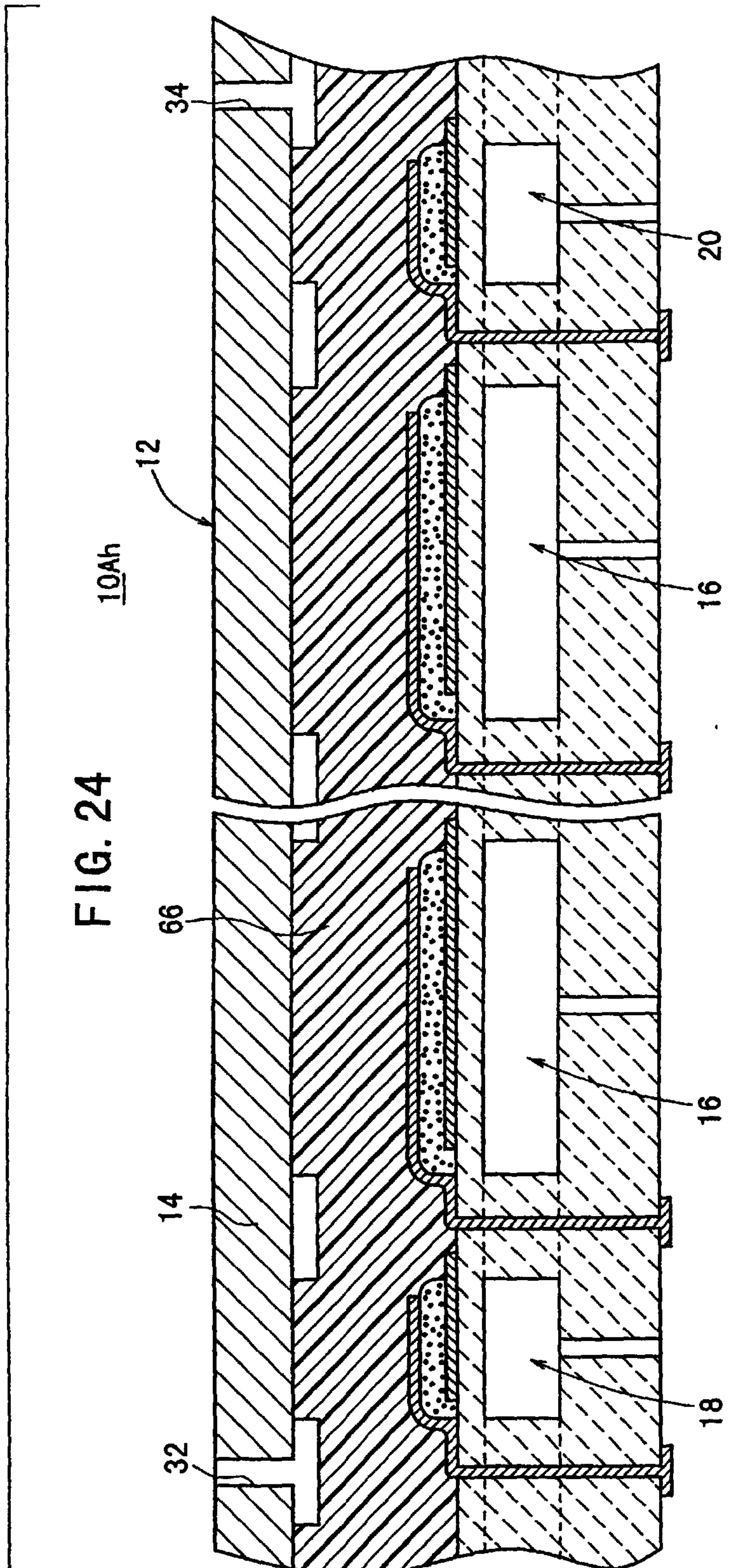


FIG. 24

FIG. 25

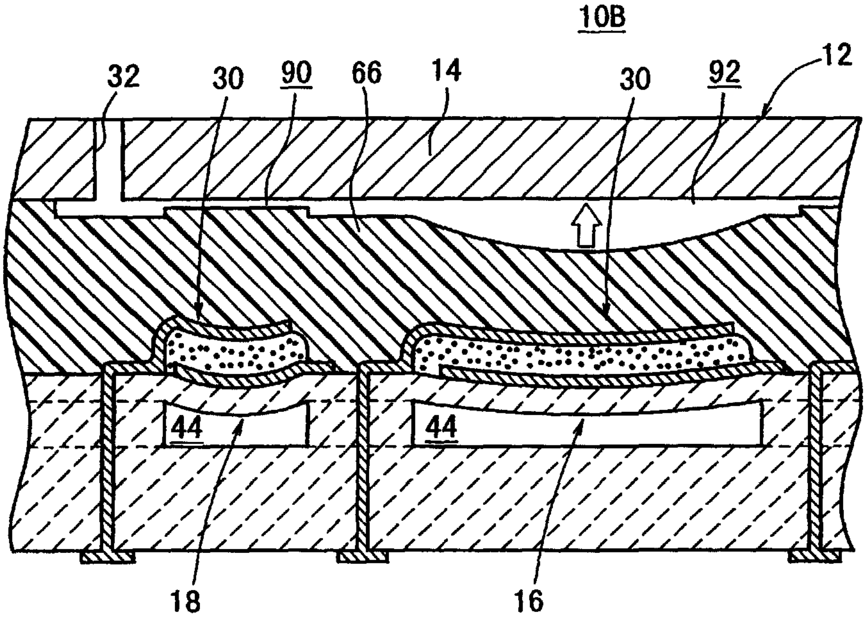


FIG. 26

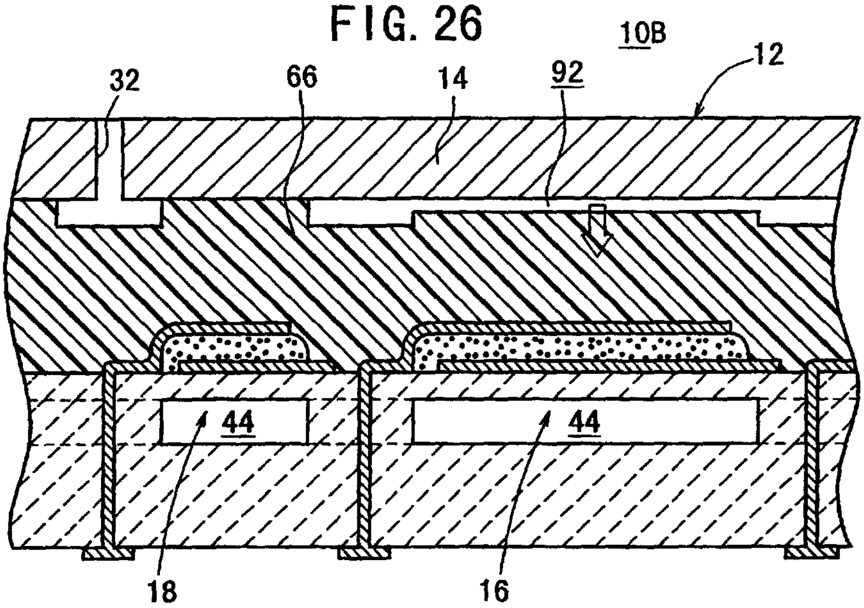


FIG. 27

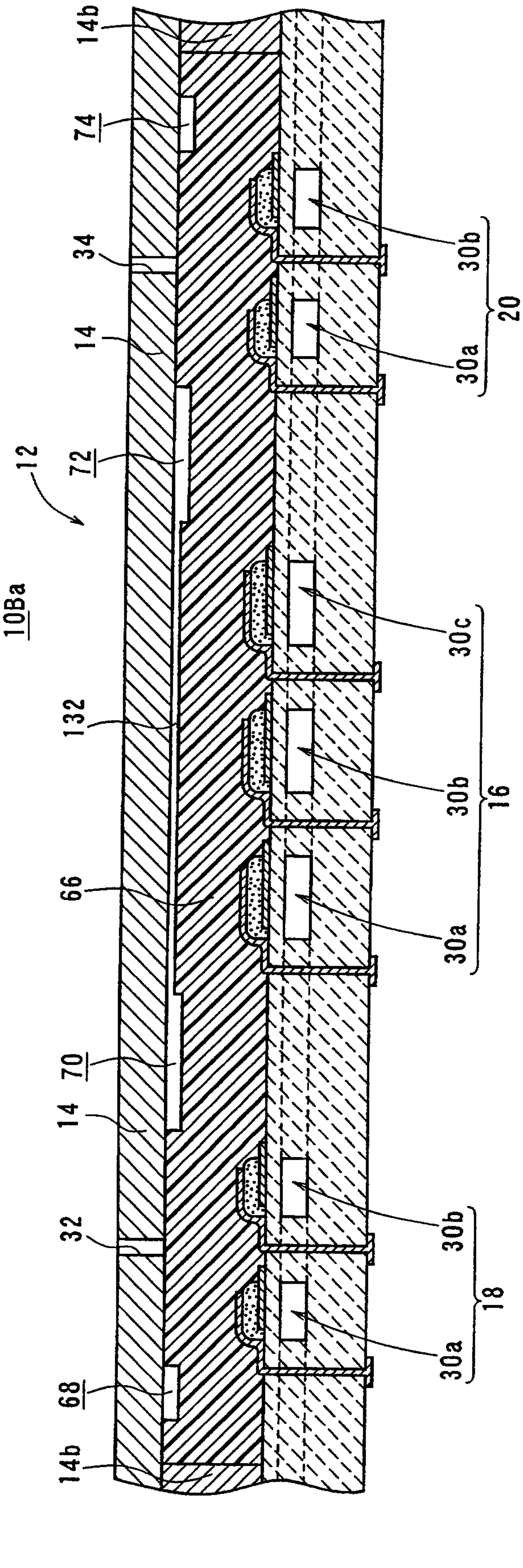
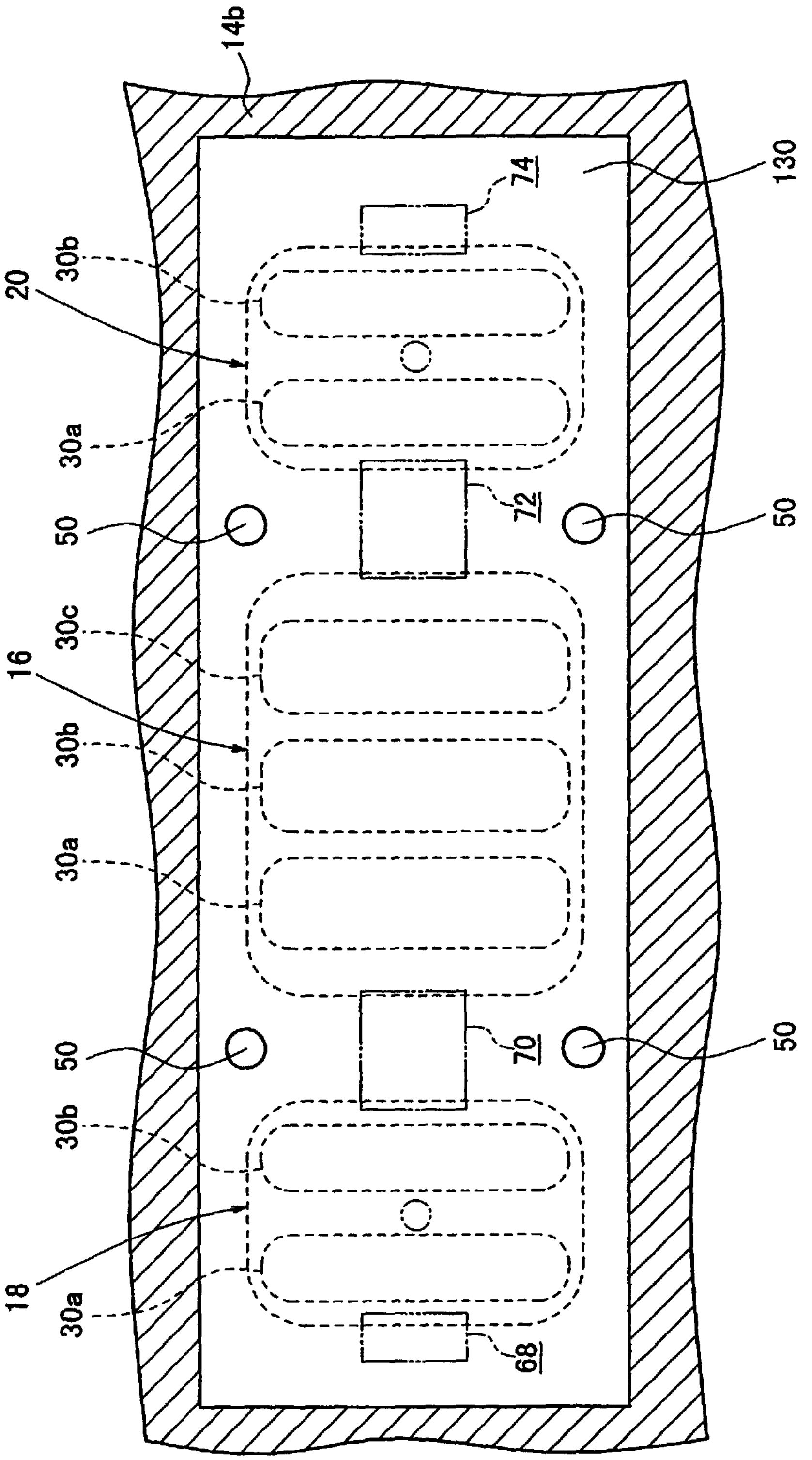
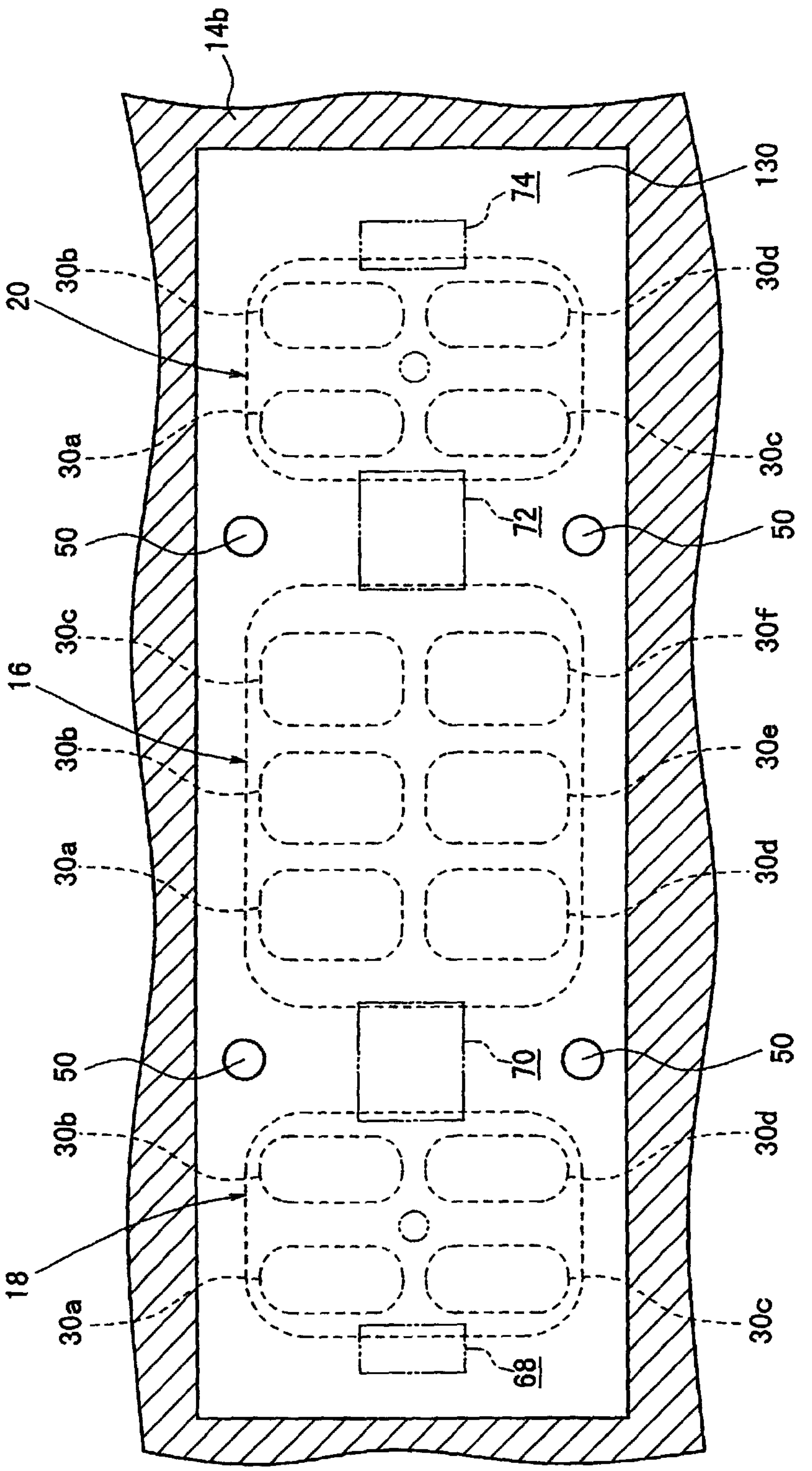

14b
74
34
14
72
12
10Ba
132
66
70
14
32
68
14b
30b
20
30a
30c
30b
16
30a
30b
18
30a

FIG. 28

10Ba



F I G. 29


14b
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74
20
30b
30d
30a
30c
72
50
10Bb
16
30c
30f
30b
30e
30a
30d
70
18
68

FIG. 30

10C

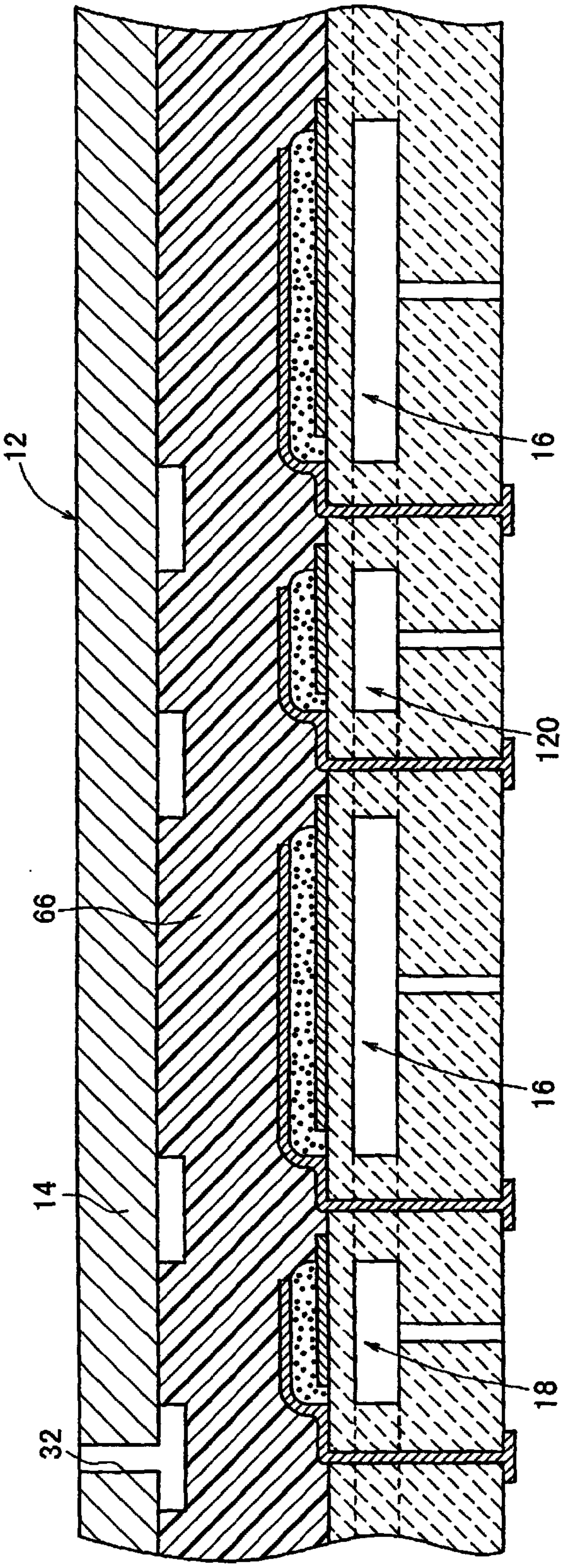


FIG. 31

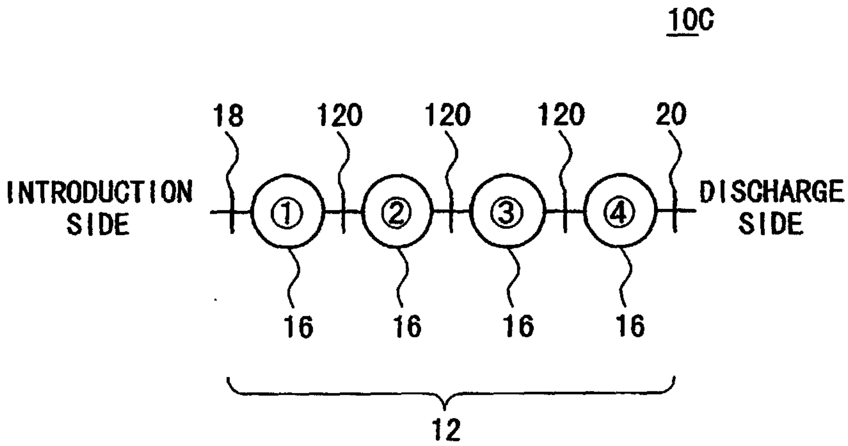

10C
18
120
120
120
20
INTRODUCTION SIDE
①
②
③
④
DISCHARGE SIDE
16
16
16
16
12

FIG. 32

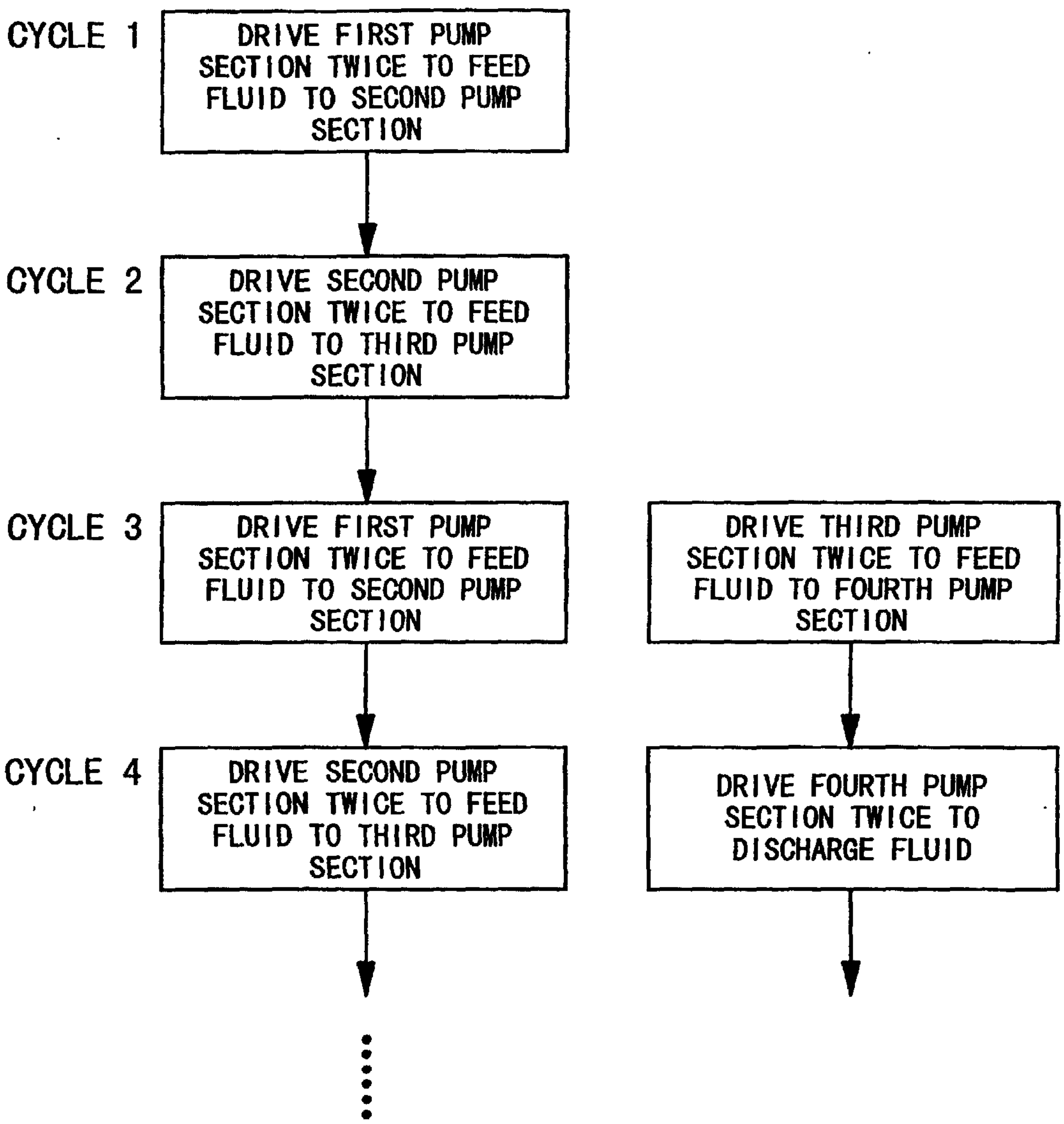

CYCLE 1
DRIVE FIRST PUMP SECTION TWICE TO FEED FLUID TO SECOND PUMP SECTION
CYCLE 2
DRIVE SECOND PUMP SECTION TWICE TO FEED FLUID TO THIRD PUMP SECTION
CYCLE 3
DRIVE FIRST PUMP SECTION TWICE TO FEED FLUID TO SECOND PUMP SECTION
DRIVE THIRD PUMP SECTION TWICE TO FEED FLUID TO FOURTH PUMP SECTION
CYCLE 4
DRIVE SECOND PUMP SECTION TWICE TO FEED FLUID TO THIRD PUMP SECTION
DRIVE FOURTH PUMP SECTION TWICE TO DISCHARGE FLUID

FIG. 33

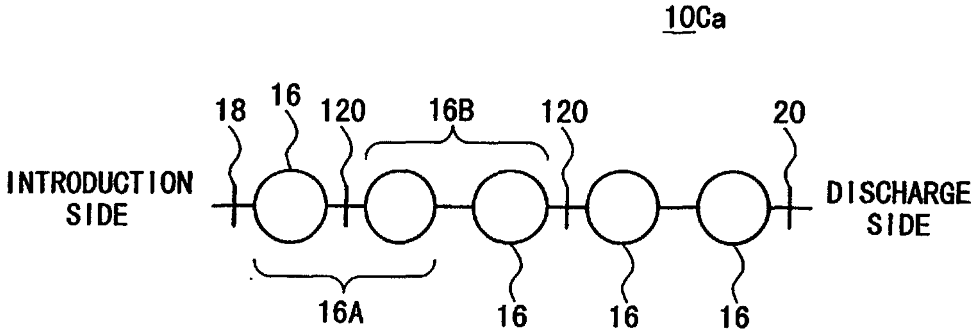

10Ca
18
16
120
16B
120
20
INTRODUCTION SIDE
DISCHARGE SIDE
16A
16
16
16

FIG. 34

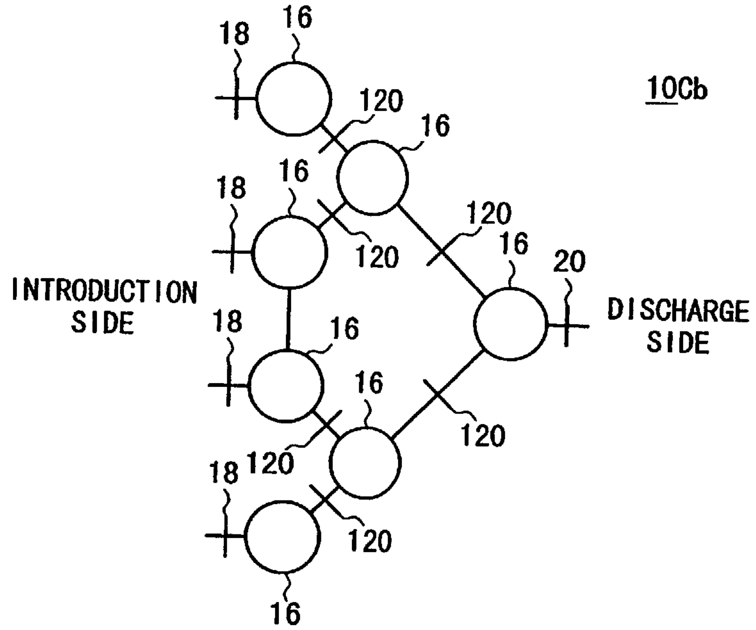

18
16
10Cb
120
16
18
16
120
120
16
20
INTRODUCTION
SIDE
18
16
DISCHARGE
SIDE
16
120
18
120
120
16

FIG. 35

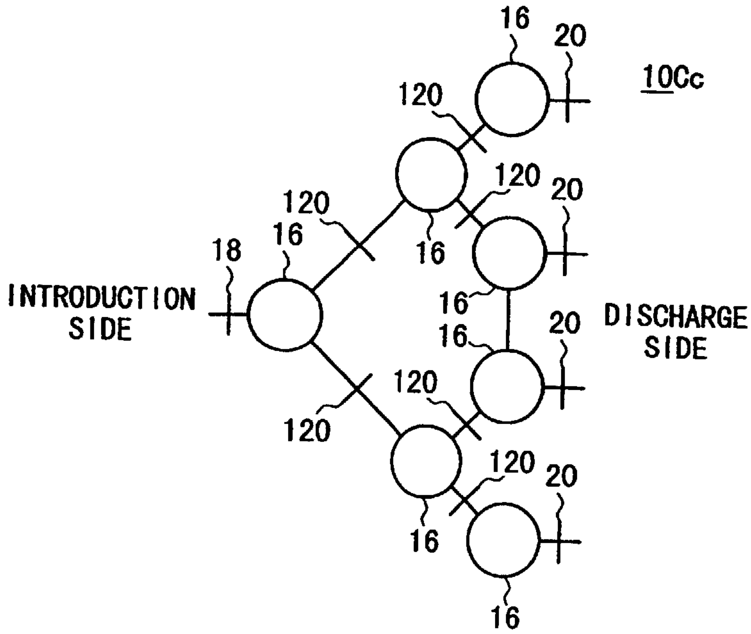

16
20
10Cc
120
120
20
120
18
16
16
INTRODUCTION
SIDE
16
16
20
DISCHARGE
SIDE
120
120
120
20
16
16

FIG. 36A

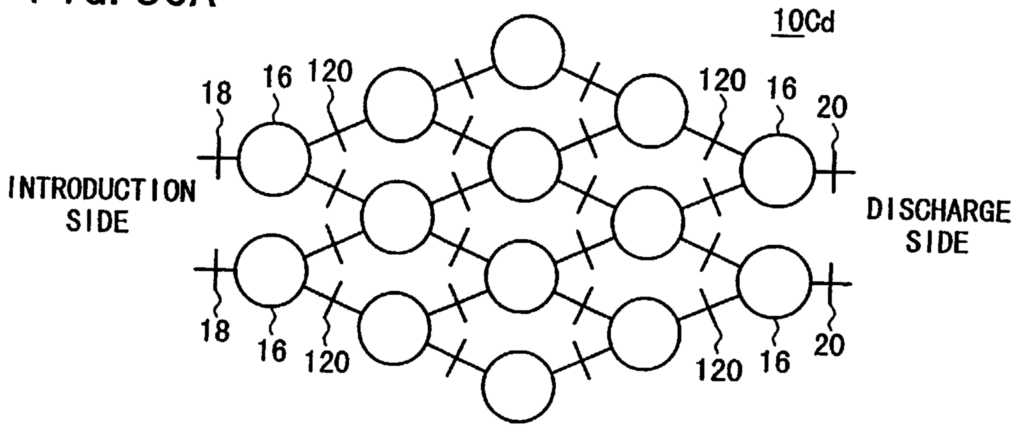


FIG. 36B

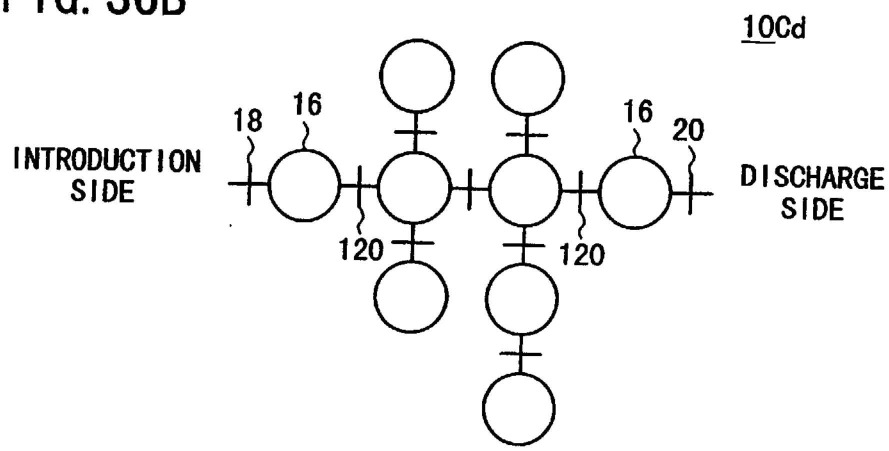


FIG. 36C

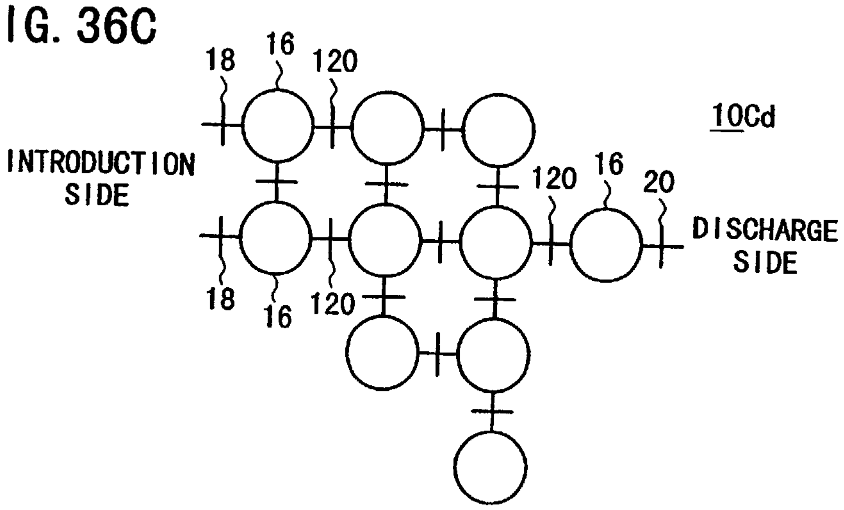


FIG. 37

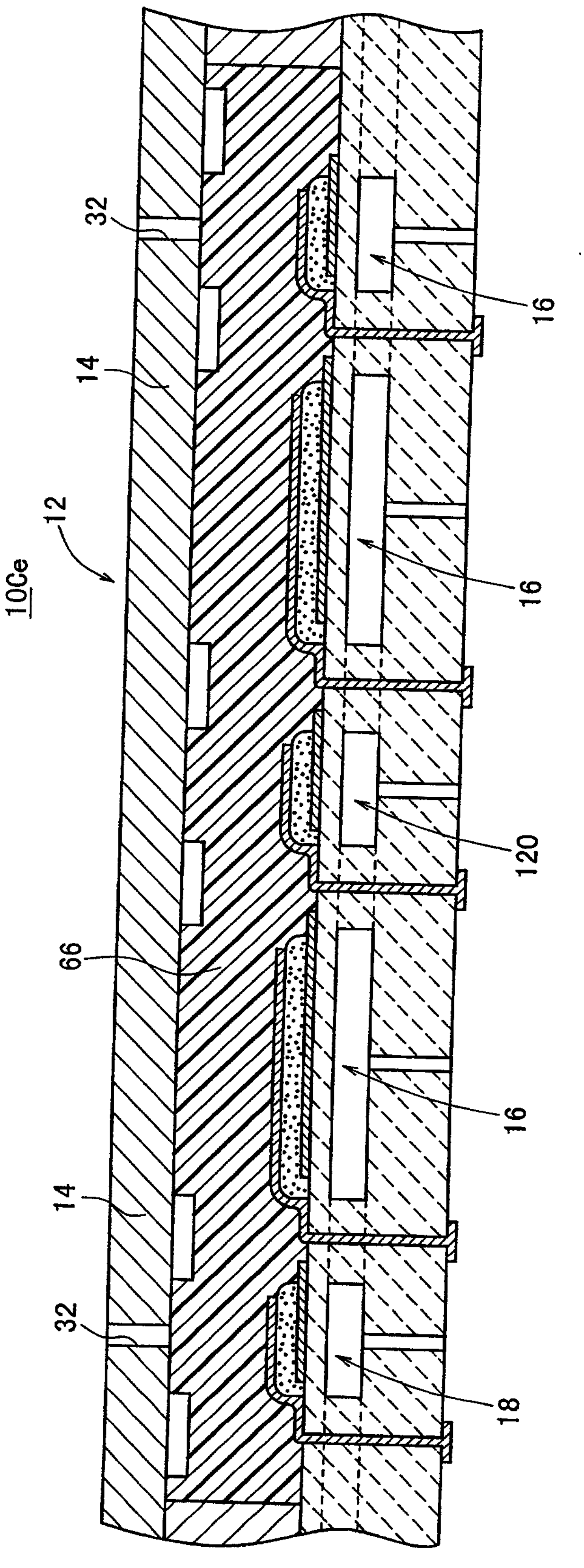


FIG. 38

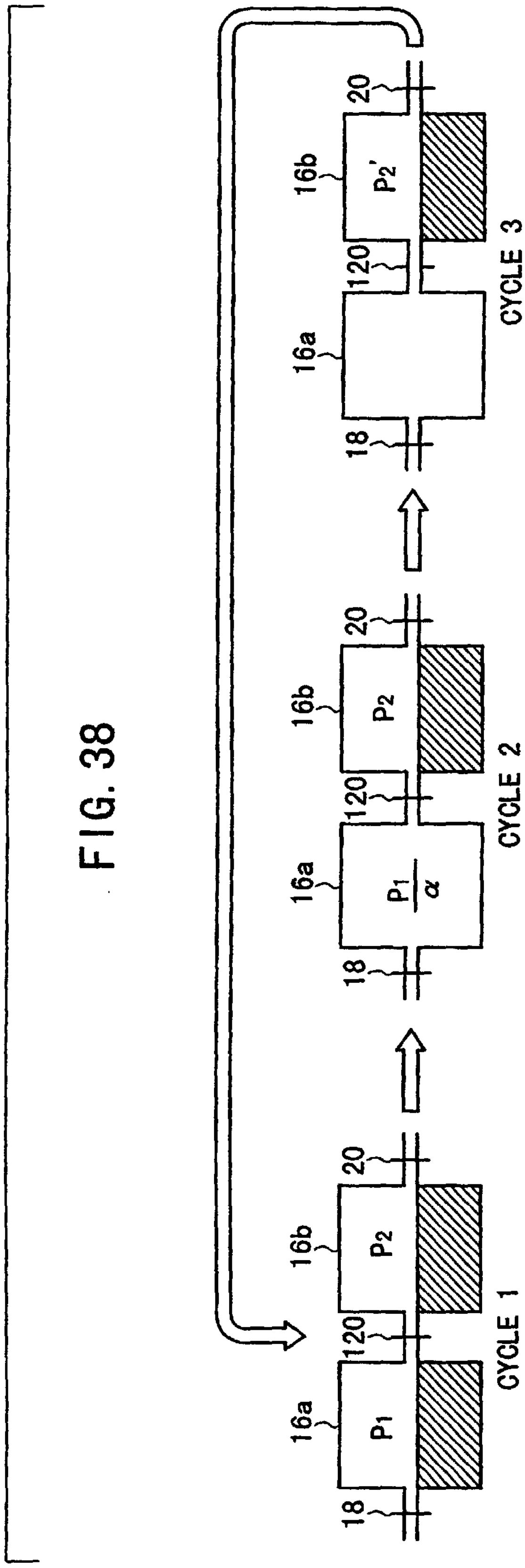

18
16a
P1
120
16b
P2
20
CYCLE 1
18
16a
P1/α
120
16b
P2
20
CYCLE 2
18
16a
120
16b
P2'
20
CYCLE 3

FIG. 39

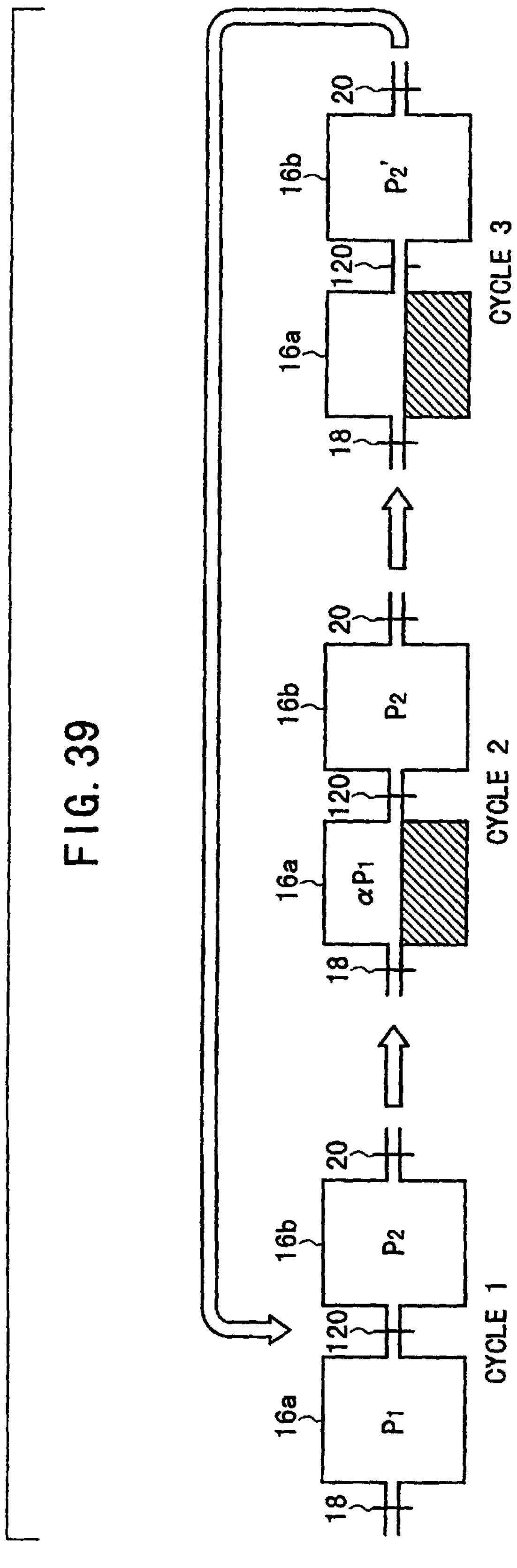

18
16a
P1
120
16b
P2
20
CYCLE 1
18
16a
αP1
120
16b
P2
20
CYCLE 2
18
16a
120
16b
P2'
20
CYCLE 3

FIG. 40A

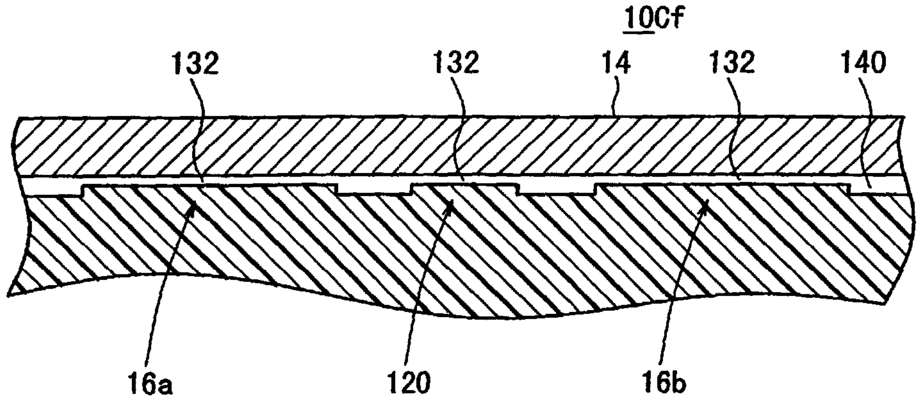
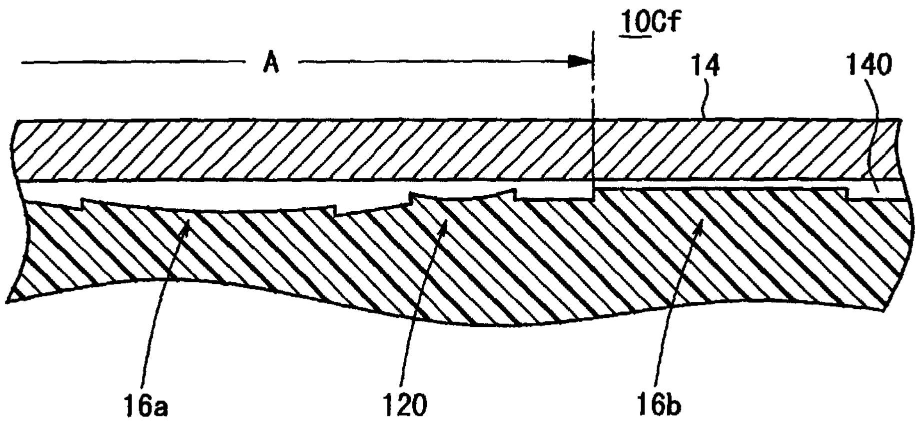


FIG. 40B



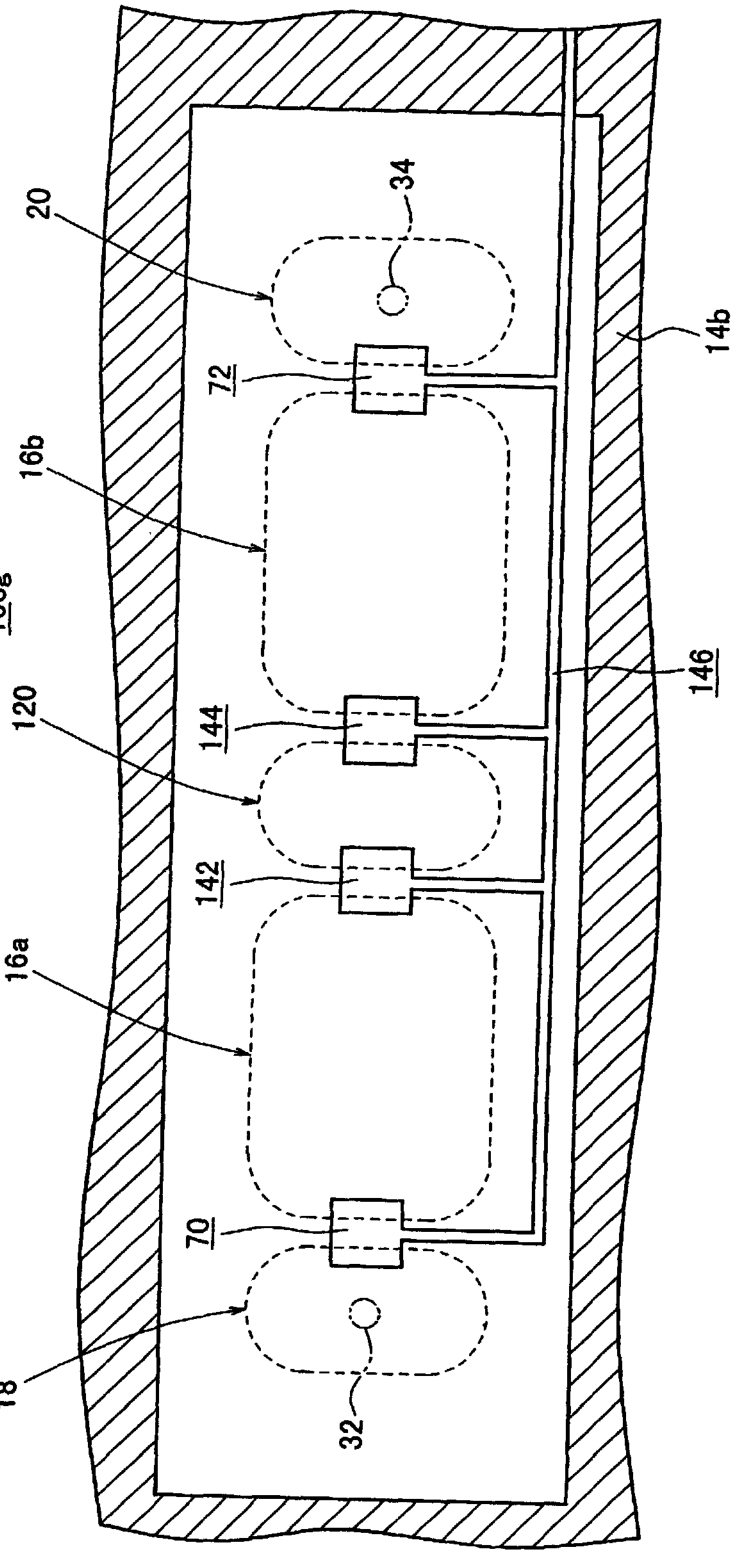


FIG. 41

FIG. 42A

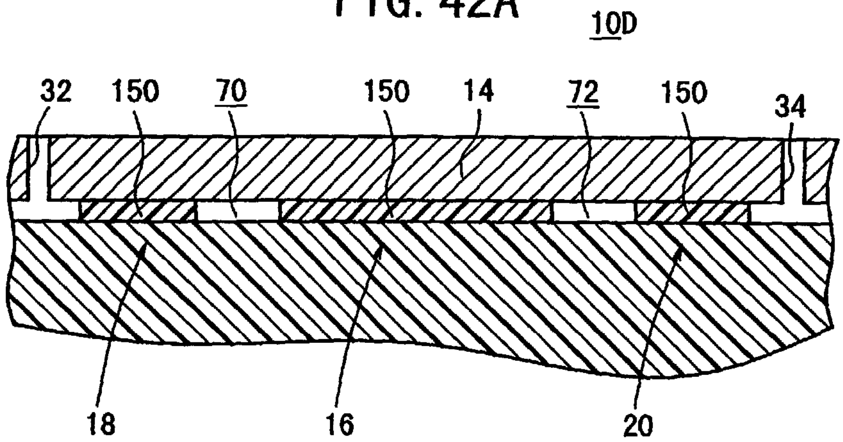
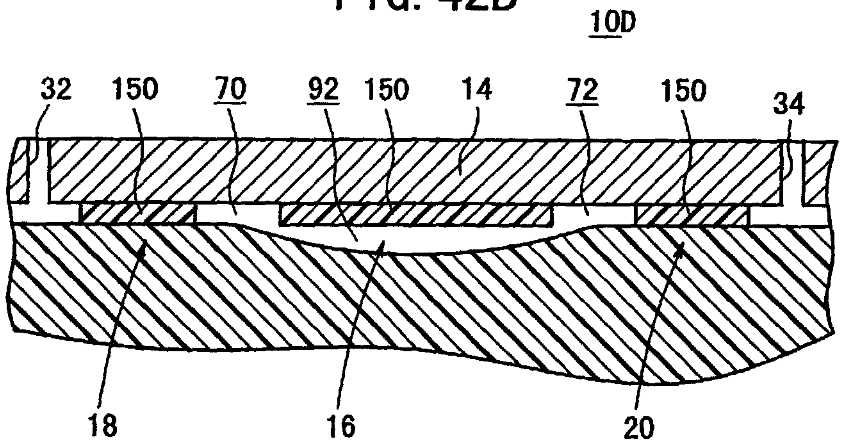


FIG. 42B



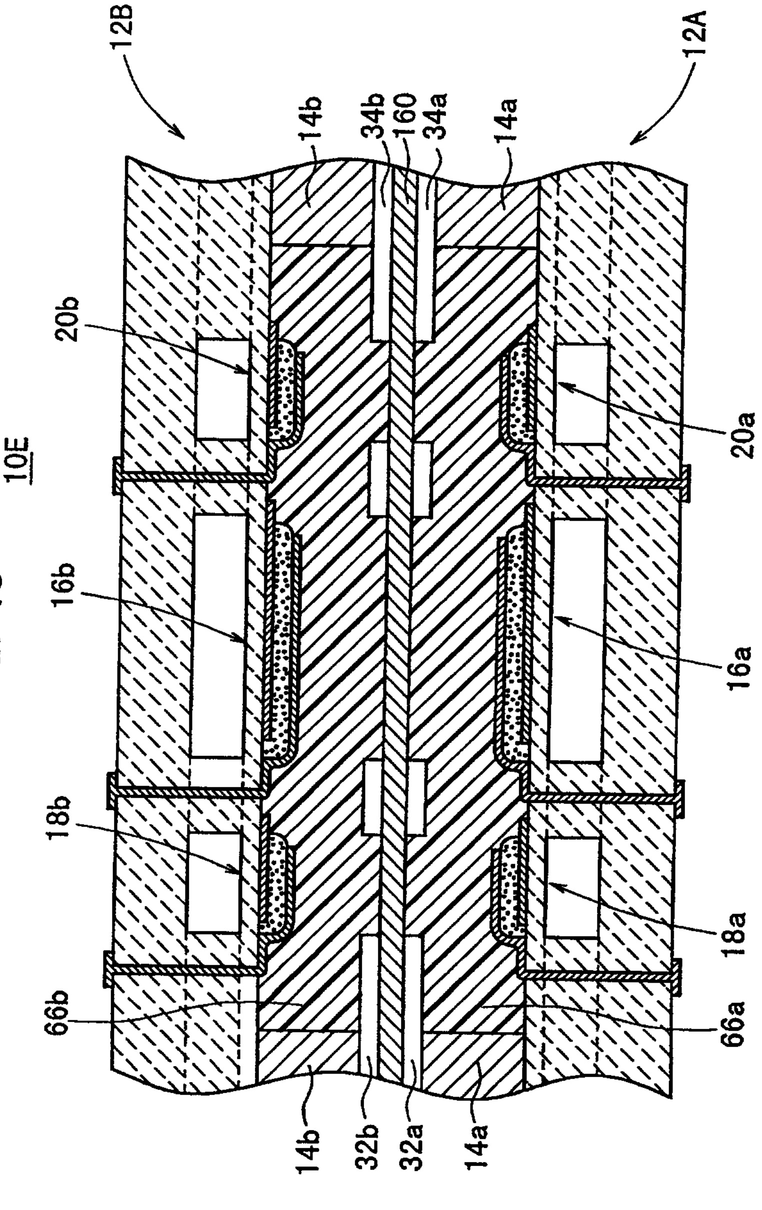
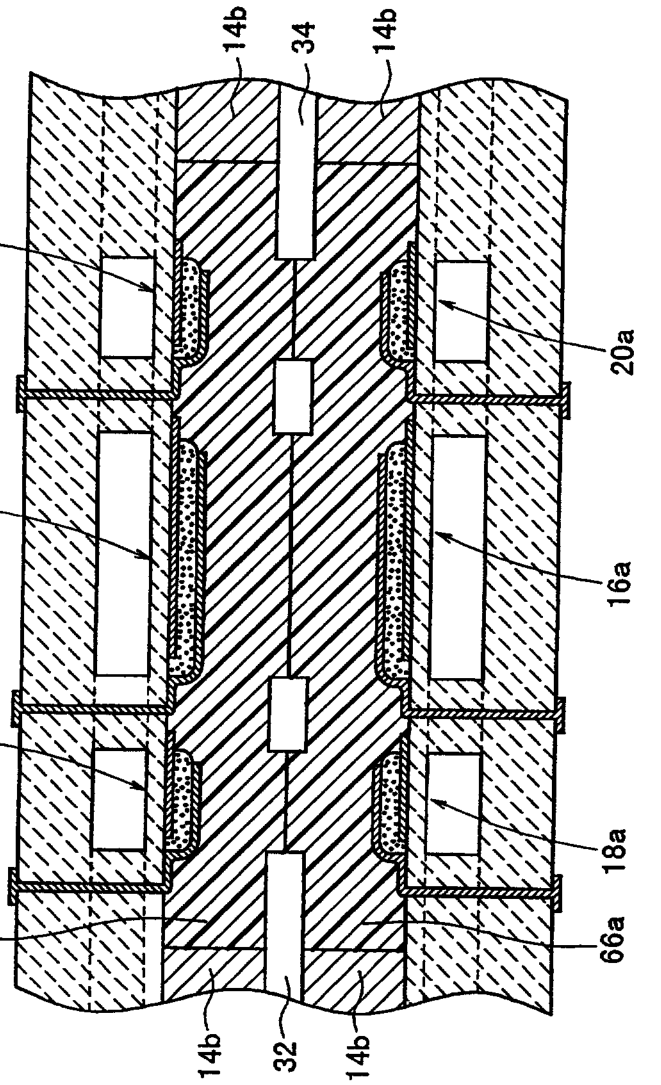

12B
12A
10E
14b
34b
160
34a
14a
20b
20a
16b
16a
18b
18a
66b
66a
14b
32b
32a
14a

FIG. 43

FIG. 44



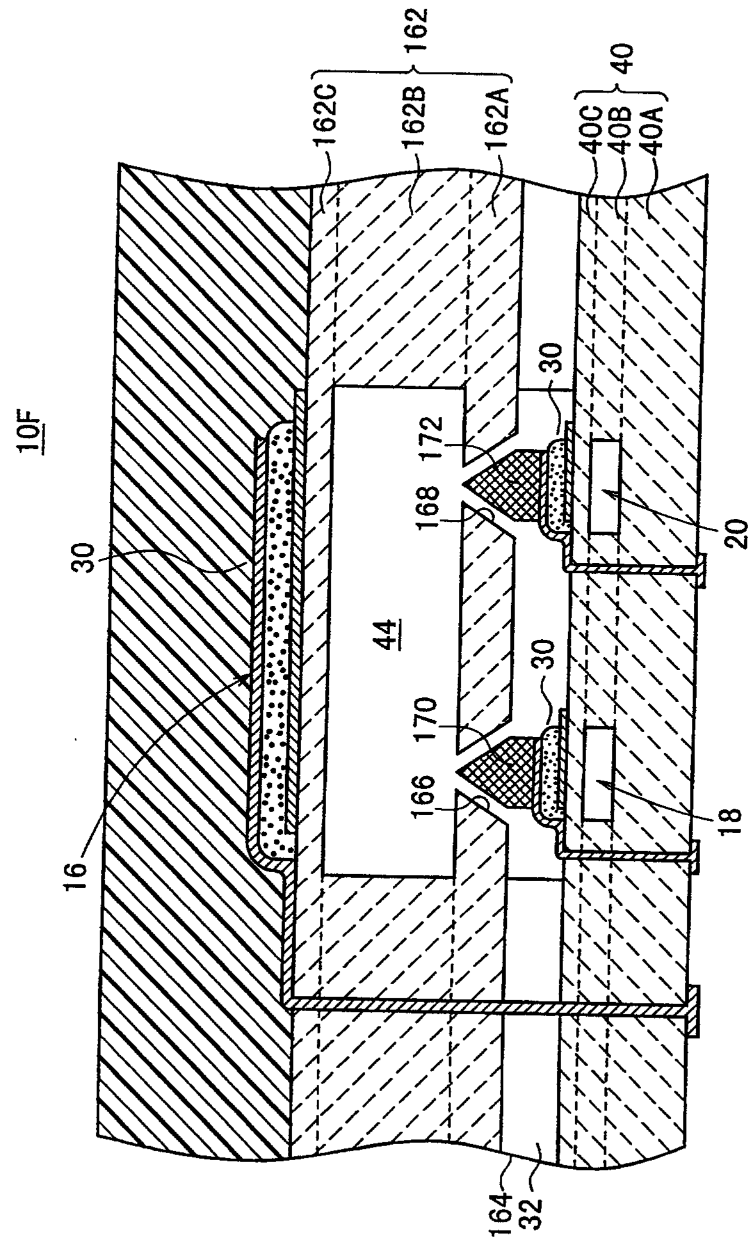

10F
162C
162B
162A
162
40C
40B
40A
40
30
172
168
44
170
166
16
20
18
164
32

FIG. 45

FIG. 46

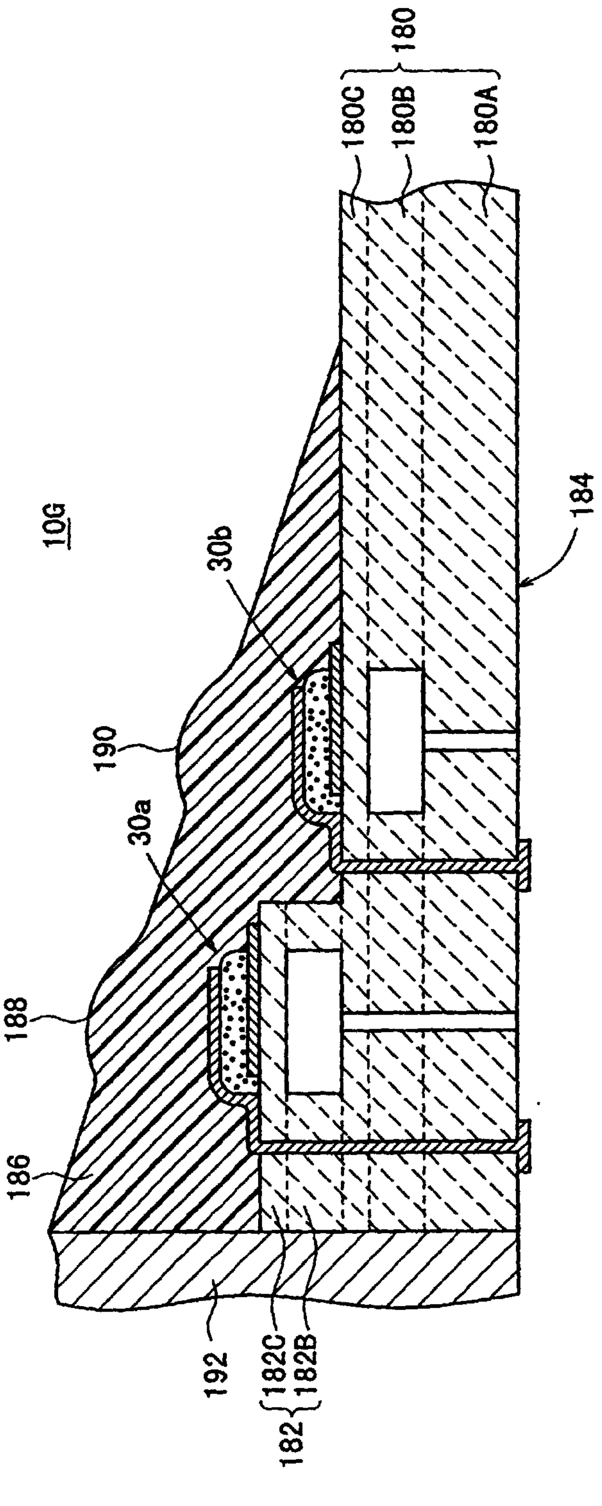

10G
180
180C
180B
180A
184
30b
190
30a
188
186
192
182C
182B
182

FIG. 47A

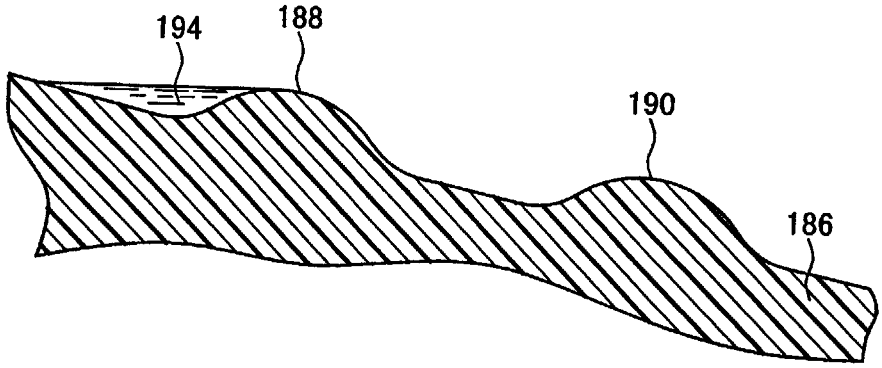


FIG. 47B

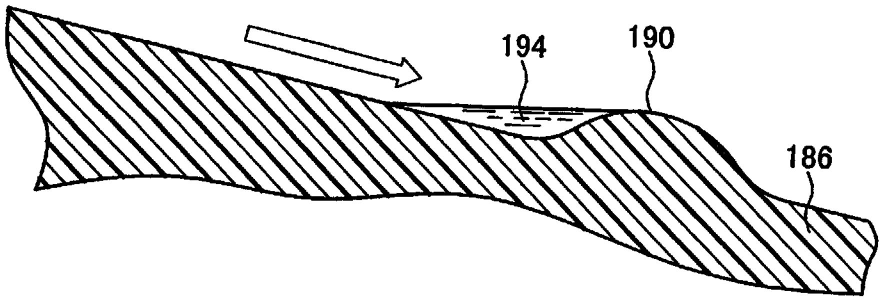


FIG. 47C

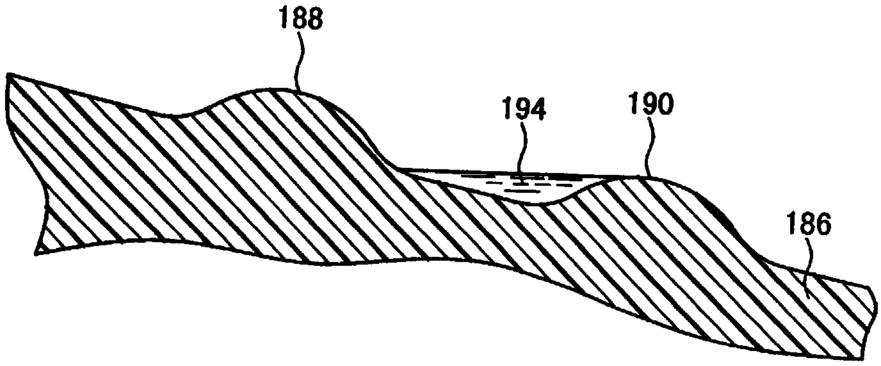
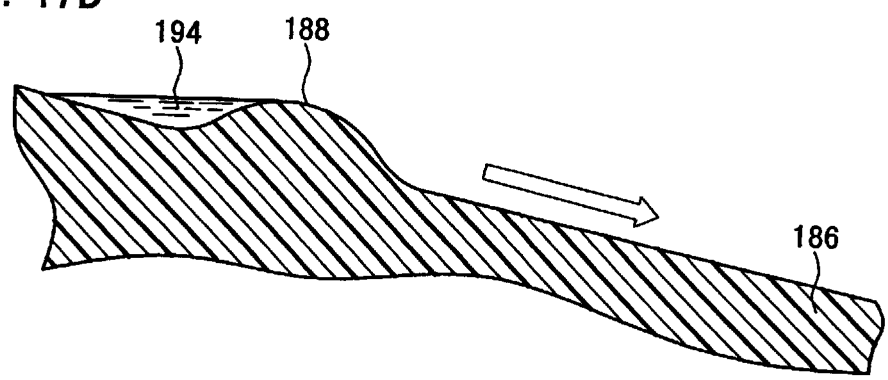


FIG. 47D



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP99/03995

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl[6] F04B43/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl[6] F04B43/00-47/14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1926-1996	Toroku Jitsuyo Shinan Koho	1994-1999
Kokai Jitsuyo Shinan Koho	1971-1999	Jitsuyo Shinan Toroku Koho	1996-1999

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP, 10-299659, A (Seiko Instruments Inc.), 10 November, 1998 (10. 11. 98) (Family: none)	1-75
Y	JP, 10-110681, A (Hitachi,Ltd.), 28 April, 1998 (28. 04. 98) (Family: none)	1-75
A	JP, 62-91676, A (NEC Corp.), 27 April, 1987 (27. 04. 87) & EP, 618733, A	1-75
Y	JP, 4-86388, A (Seiko Epson Corp.), 18 March, 1992 (18. 03. 92) (Family: none)	12-75
A	JP, 10-78549, A (NGK Insulators,Ltd.), 24 March, 1998 (24. 03. 98) & US, 5862275, A	1-75
Y	JP, 5-202857, A (NEC Corp.), 10 August, 1993 (10. 08. 93) (Family: none)	1-75

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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Date of the actual completion of the international search 24 September, 1999 (24. 09. 99)	Date of mailing of the international search report 12 October, 1999 (12. 10. 99)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)